Proceedings of the NORTH DAKOTA Academy of Science

89th Annual Meeting

April 1997 Volume 51

The Proceedings of the North Dakota Academy of Science (ISBN 0096-9214) is published annually in April. This issue contains symposia articles, professional communications, and communications from the collegiate competition sessions (Denison competition). These articles and communications represent the papers submitted and accepted for presentation at the April annual meeting of the Academy.

Correspondence concerning subscriptions (standing orders), as well as instructions for authors and other related matters, should be directed to:

Office of the Secretary-Treasurer
North Dakota Academy of Science
PO Box 7081
Grand Forks, North Dakota 58202
USA

Printed by Knight Publishing
Fargo, North Dakota

PROCEEDINGS
OF THE
NORTH DAKOTA ACADEMY OF SCIENCE

Volume 51 April 1997

NORTH DAKOTA ACADEMY OF SCIENCE

(Official State Academy; Founded December 1908)

1996-1997

89th Annual Meeting

April 24-25, 1997

Grand Forks, North Dakota

The Proceedings of the North Dakota Academy of Science (NDAS) was first published in 1948 with Volume I reporting the business and scientific papers presented for the 40th annual meeting, May 2 -3, 1947. Through Volume XXI, the single yearly issue of the Proceedings included both abstacts and full papers. Commencing with Volume XXII, the Proceedings was published in two parts. Part A, published prior to the annual meeting, contained an abstract of each paper to be presented at the meeting. Part B, published later, contained full papers by some of the presenters.

Commencing in 1979 with Volume 33, the Proceedings changed to the present 8 1/2 x 11 inch format. It is produced from camera-ready copy submitted by the authors and issued in a single part to be distributed initially at the annual meeting. For the current Volume, all submissions were on computer disk; the entire Proceedings was then assembled by using desktop publishing software. This approach allowed the Editor control over all formatting and many of the papers were reformatted, giving the Proceedings a more consistent look. Also, incorporating all of the submissions on computer allowed production of an electronic copy of the Proceedings for the first time.

Each Collegiate and Professional presentation at the annual meeting is represented by a full page communication which is more than an abstract, but less than a full paper. The communications contain actual results and conclusions, and permit data presentation. The communication conveys much more to the reader than did the abstract, but still provides the advantage of timeliness and ease of production. Commencing with Volume 50, presenters of the Symposia of the 88th annual meeting were given the opportunity to contribute an expanded or full length article consisting of a multiple page contibution thus providing a presentation of much greater depth and scope than possible in a singe page communication.

The communications of this volume of the Proceedings are presented in three sections. The first section contains presentations from the symposium offered at the 89th annual meeting. These papers are organized in the same sequence as presented in the respective symposium.

The second section contains the collegiate communications representing all of the papers presented in the A. Roger Denison Student Research Paper Competition. Undergraduate and graduate students reported on the results of their own research activities, usually carried out under the guidance of a faculty advisor. While student competitors were required to prepare a communication similar to those prepared by their professional counterparts, these communications were not reviewed by the NDAS Editorial Committee prior to publication herein. The Denison Awards Committee judges the oral presentation and the written communication in arriving at their decision for first and runner-up awards in both the graduate and undergraduate student competitions. In this section the first group of papers is from the undergraduate competition and the second group is from the graduate competition. The papers in both groups are listed alphabetically by first author.

The third section of this volume contains the communications presented in the professional sections of the annual meeting. All professional communications were reviewed by the Editorial Committee prior to their acceptance for presentation and publication herein. The papers in this section are also listed alphabetically by first author.

Readers may locate communications by looking within the major sections of these Proceedings (see table of contents) or by referring to the author index.

This issue of the Proceedings also contains the Constitution and Bylaws of the Academy, a list of officers and commmitte members, a list of all Academy members as of March 1997, a copy of minutes from last year's annual meeting, a listing of past presidents of the Academy, and a copy of the 1995 and 1996 financial statements.

Eric Uthus

Editor's Notes 2
Symposium: The Devils Lake Basin: A Scientific Perspective 4
Symposium: Problems and Prospects for Community Development in North Dakota 61
Symposium: Applications of Statistical Modeling Methods 86
Symposium: Astronomy in North Dakota - From the Solar System to the Universe of Galaxies 105
Symposium: Technical Aspects of Coal Combustion By-Products Commercial Utilization 125
Workshop: Information in the Electronic Age - How to Get It and How to Use It 142
Communications - Undergraduate 145
Communications - Graduate 160
Communications - Professional 180
Constitution of the North Dakota Academy of Science 225
Minutes of the 1996 Annual Business Meeting 229
Academy Officers and Committees 232
Past Presidents and Location of the Annual Meeting 234
Statement of Financial Status 235
Obituary 238
Membership of the North Dakota Academy of Science 239
Author Index 245

SYMPOSIUM: THE DEVILS LAKE BASIN: A SCIENTIFIC PERSPECTIVE

THE DEVILS LAKE BASIN: TROUBLED WATERS
Roger A. Hollevoet*
U.S. Fish and Wildlife Service, Devils Lake Wetland Management District, Devils Lake, ND 58301

GEOLOGIC HISTORY OF THE DEVILS LAKE BASIN, ND
John R. Reid*[1] and John P. Bluemle[2]
[1]Department of Geology and Geological Engineering, University of North Dakota, Grand Forks, ND 58202-8358
[2]North Dakota Geological Survey, 600 E. Boulevard Ave, Bismarck, ND 58505-0840

SOILS AND STRAND LINES OF DEVILS LAKE, NORTH DAKOTA
J. L. Richardson* and C. L. Lura
Department of Soil Science, North Dakota State University, Fargo 58105
Biology Department, Minot State University-Botineau, Botineau 58318

VEGETATION IN THE STRAND ZONES OF DEVILS LAKE, NORTH DAKOTA
C. L. Lura*[1] and J. L. Richardson[2]
[1]Biology Department, Minot State University-Bottineau, Bottineau, 58318
[2]Department of Soil Science, North Dakota State University, Fargo, 58105

ARCHAEOLOGICAL STUDIES IN THE DEVILS LAKE BASIN
Fred Schneider* and Dennis Toom
Department of Anthropology, University of North Dakota, Grand Forks, ND 58202

THE DEVILS LAKE FISHERY HISTORICAL, CURRENT AND FUTURE PERSPECTIVES
Terry R. Steinwand*
North Dakota Game and Fish Department, 100 North Bismarck Expressway, Bismarck, ND 58501

PHYTOPLANKTON DYNAMICS IN DEVILS LAKE UNDER VARYING HYDROLOGIC CONDITIONS
Harry V. Leland* and Wayne R. Berkas
U. S. Geological Survey, 3215 Marine Street, Boulder, CO 80303, and 821 East Interstate Ave., Bismarck, ND 58501

HISTORICAL CLIMATE OF THE DEVILS LAKE REGION
Paul E. Todhunter*
Department of Geography, University of North Dakota, Grand Forks, ND 58202-9020

A HISTORY OF LAKE-LEVEL FLUCTUATIONS FOR DEVILS LAKE, NORTH DAKOTA, SINCE THE EARLY 1800'S
Gregg J. Wiche*, U.S. Geological Survey, Water Resources Division, 821 East Interstate Avenue, Bismarck, ND 58501
R.M. Lent, U.S. Geological Survey, Water Resources Division, 28 Lord Road, Suite 280, Marlborough, MA 01752
W.F. Rannie, Department of Geography, University of Winnipeg, Winnipeg, Manitoba, R3B 2E9, Canada
Aldo V. Vecchia, U.S. Geological Survey, Water Resources Division, 821 East Interstate Avenue, Bismarck, ND 58501

USING CONDITIONAL SIMULATIONS OF THE LEVEL OF DEVILS LAKE, NORTH DAKOTA, TO RECONSTRUCT HISTORICAL HYDROLOGIC CONDITIONS
Aldo A. Vecchia*, U.S. Geological Survey, Water Resources Division, 821 East Interstate Avenue, Bismarck, ND 58501
Gregg J. Wiche, U.S. Geological Survey, Water Resources Division, 821 East Interstate Avenue, Bismarck, ND 58501

IMPORTANCE OF BOTTOM-SEDIMENT PROCESSES TO MAJOR-ION AND NUTRIENT BUDGETS OF DEVILS LAKE, NORTH DAKOTA

Robert M. Lent*, U.S. Geological Survey, Water Resources Division, 28 Lord Road, Suite 280, Marlborough MA 01752
Gregg J. Wiche, U.S. Geological Survey, Water Resources Division, 821 East Interstate Avenue, Bismarck, ND 58501

DEVILS LAKE BASIN UPPER BASIN FLOOD STORAGE POTENTIAL

Lee Klapprodt*
North Dakota State Water Commission, 900 E. Blvd., Bismarck, ND 58505

DEVILS LAKE EMERGENCY OUTLET PLAN (EOP)

Todd Sando*, P.E.
North Dakota State Water Commission, 900 East Boulevard Avenue, Bismarck, ND 58505

THE HUMAN-ECONOMIC ASPECT OF THE DEVILS LAKE BASIN

Dr. Lowell R. Goodman* and Kirk Jensen
Department of Geography, University of North Dakota, Grand Forks, ND 58202-9020

THE DEVILS LAKE BASIN: TROUBLED WATERS

Roger A. Hollevoet*
U.S. Fish and Wildlife Service, Devils Lake Wetland Management District, Devils Lake, ND 58301

I. INTRODUCTION

The Devils Lake Basin is located in northeastern North Dakota and encompasses an area of 3,814 square miles or 2,440,960 acres. About 3,320 square miles are tributary to Devils Lake and the remaining is tributary to Stump Lake. Devils Lake is considered a closed basin. The Basin is part of the Red River Basin but is classified as non-contributing, as waters from the Devils Lake Basin rarely overflow into the Red River Basin. At elevation 1445' above sea level (amsl) water will flow from the eastern part of the lake into Stump Lake and at 1457' amsl water will flow from the Stump Lakes into the Sheyenne River. Levels in February 1997 were approaching elevation 1438' M.S.L., closing in on a one hundred thirty-year high.

The Devils Lake Basin is made up of nine separate watersheds or subbasins located in parts of eight different counties and most of these drain into Devils Lake via a system of small coulees. These subbasins are the Little Coulee Subbasin (421 sq. mi.), Mauvis (882 sq. mi.), St. Joe/Calio (233 sq. mi.), Starkweather (391 sq. mi.), Edmore (501 sq. mi.), Comstock (58 sq. mi.), Devils Lake north and south slopes (512 and 328 sq. miles respectively) and the Stump Lake subbasin (488 sq. mi.) (1).

Devils Lake itself is a chain of connecting water bodies or bays that totaled about 45,000 surface acres in 1992 and in February of 1997 covers about 80,000 surface acres. These bays include, from west to east, the Minnewaukan Flats, West Bay, Main Bay, East Bay and East Devils Lake.

Physiographically, the basin lies within the Central Lowlands Province, an area of glacial drift and lacustrine plains formed by continental ice sheets during the last glaciation. The topography of the Basin is glacial in origin with gently rolling low hills and broad flat lands composed of rich soils dotted with many wetlands and small lakes.

The combination of productive soils, grasslands, and a diversity of wetland types created an ecotype rich in prairie/wetland flora and fauna. This area is known as the Northeastern Drift Prairie within the Prairie Pothole Region. This subregion is based on glacial landforms, environmental conditions, and biogeographical relationships.

The climax biotic community of this region was represented by the eastern mixed-grass prairie and, in some smaller areas, the tall grass prairie. These grasslands were interspersed with wetlands exhibiting seasonal, temporary, semipermanent, and permanent water regimes.

II. CHANGES IN THE DEVILS LAKE BASIN

The Devils Lake Basin lies predominately in a grassland biome and, prior to settlement by white man, great expanses of treeless prairie was the major habitat type. There were some tracts of woodland limited to floodplain areas and in the hills around Devils Lake. Natural wetlands of glacial origin were numerous and natural drainage was unintegrated.

Land use by white man since the late 1800's has caused drastic changes in habitat conditions, often resulting in a general environmental deterioration. Agricultural crops have replaced the native prairie sod changing the landscape from grassland to small grains and row crops. Many of these areas became subject to wind and water erosion. Although these areas are now extremely productive for agricultural commodities, the outlook for many breeding birds and species diversity has been changed (2).

In addition to the changes to the uplands or original grassland biome, numerous natural wetlands have been drained for agricultural production. The ecosystem that once was composed of mixed and tall grass prairie and diverse wetland habitats is now dominated by agricultural production. According to a report entitled "The Devils Lake Basin Water Management Plan" (1) a Soil Conservation Service land use analysis shows that 78-91 percent of the land in the Devils Lake Basin counties are in agricultural production. A Natural Resource Conservation Service analysis on hydric soils and a Fish and Wildlife Service National Wetland Inventory (NWI) study states that a minimum of 189,000 acres of wetlands has been drained in the Devils Lake Basin (3).

III. MIGRATORY BIRD RESOURCES

Despite these dramatic changes in the landscape, wildlife resources still exist in the basin. Tame grasslands have replaced the native grasses and occur on U.S. Fish and Wildlife Service lands, N.D. Game and Fish Department lands, and scattered on private lands enrolled in the Conservation Reserve Program (CRP) and other conservation programs like Water Bank. Approximately 200,000 wetland acres (NWI data) remain in the basin (3). These habitats mimic the original prairie habitats for some species. Migratory birds that are typically found in the area that are dependant or associated with wetland habitats include the following (2):

Grebes
Eared Grebe
Western Grebe
Pied Billed Grebe
Horned Grebe
Red Necked Grebe

Waterfowl
Tundra Swan
Canada Goose
Mallard
Gadwall
Pintail
Blue-Winged Teal
Northern Shoveler
Canvasback
Redhead
Ruddy Duck
Wood Duck
American Wigeon
American Green-Winged Teal
Lesser Scaup
Ringed Neck Duck
Black Duck
Bufflehead
Common Goldeneye
Hooded Merganser
Common Merganser
Snow Goose
White-fronted Goose
Ross Goose

Pelicans/Cormorants
White Pelican
Double-Crested Cormorant

Shorebirds, Gulls, Terns
Piping Plover
Killdeer
Upland Sandpiper
Willet
Marbled Godwit
American Avocet
Wilsons Phalarope
Spotted Sandpiper
Greater Yellowlegs
Lesser Yellowlegs
Franklin's Gull
Bonaparte's Gull
Ring-Billed Gull
California Gull
Forester's Tern
Common Tern
Black Tern

Herons, Cranes, Rails
Sora
Virginia Rail
Yellow Rail
American Coot
American Bittern
Black-Crowned Night Heron
Great Blue Heron
Great Egret
Snowy Egret
Cattle Egret
Sandhill Crane

Passerines and other
Long-Billed Marsh Wren
Short-Billed Marsh Wren
Common Yellowthroat
Red-winged blackbird
Yellow-headed blackbird
Savannah Sparrow
Sharp-tailed Sparrow
Brown-Headed Cowbird
Tree Swallow
Belted Kingfisher

Birds of Prey
Bald Eagle
Northern Harrier

IV. COMPLEX ISSUES OF THE DEVILS LAKE BASIN

Devils Lake is a shallow, saline, hypereutrophic lake. Water levels have varied widely over time. The specific reasons for the long term fluctuations are not well understood in spite of various scientific investigations. Yearly variations in precipitation, long term climatic fluctuation, recent changes in drainage patterns by man, and unusual hydrologic characteristics of the basin all play a role (4).

No documented records of lake levels are available before 1867 but, using tree ring chronology, Upham (1895) (5), estimated Devils Lake was at elevation 1441' amsl in 1830. According to studies by Blumele (1991) (1) the lake probably overflowed its natural outlet sometime in the last 1800 years. Lake levels were recorded sporadically from 1867 until 1901 when the U.S. Geological Survey installed a gauging station on Devils Lake (5). In 1867 the lake was recorded at a maximum of 1438.4' amsl and was down to a record of 1400.9' amsl in 1940. The lake fluctuated from 1940 until it reached a peak of 1428.8' amsl in 1987, which at that time was the highest level for the century. The drought of the late nineteen eighties then came into play and the lake declined to 1422.6' amsl in 1993. That drought was immediately reversed into a wet period starting in June, 1993 until the current period of February 1997 when the lake is at 1437.8' amsl.

Water quality is also an issue in the Devils Lake chain. Since Devils Lake is a closed basin, levels of salts and nutrients continue to rise. Various studies have been completed on nutrient loading but it has been recommended that a nutrient budget be completed for the lake and its watershed and that possible watershed management practices be implemented to try to lower nutrient loads into the lake. Salts are also a concern in Devils Lake. In a January 1995 State Water Commission report (1) it stated that a 1989 study with eight water sampling sites showed water quality varied from west to east in the lake. The samples varied from 2,500 parts per million (PPM) total dissolved solids in the Minnewaukan flats to 10,700 PPM in East Devils Lake.

The issues of water quality and quantity are most frequently visited by conservationists, agriculturalists, recreationists and the general public living in Devils Lake. Some of the issues that are frequently brought up include nutrient loading in Devils Lake and in area wetlands. This often pits conservation issues against agricultural producers. The claim is that agricultural fertilizers are adding to the nutrient levels in Basin waters. U.S. Geological Survey and N.D. Department of Health have been studying this issue and many are recommending a complete nutrient load review be done for the Basin and a watershed plan be implemented to address this issue. More frequent monitoring and complete data are needed in this area (6). Many recreationalists already have formed opinions on nutrient loading based on the "green" lake conditions each year with floating mats that give fishing and boating enthusiasts much frustration.

Water quality, in terms of total dissolved solids, is also an issue to many individuals. Fishermen complain about the salts that form on their expensive equipment, but of most concern is the salts, particularly the sulfates, in the Devils Lake water column and the impacts it could have downstream on users of the water if an outlet is constructed. The water quality standards for sulfates as outlined in a February 1996, Corps of Engineers Report (7) in the Sheyenne River are 450 mg/l. In the Red River and at the International border between Canada and the United States the standard is 250 mg/l. Approximately half of Devils Lake's total dissolved solids (TDS) is sulfates. In October of 1992, Main Bay TDS was 4120 mg/l at elevation 1423. In October 1995, at elevation 1435 the TDS levels in Main Bay were 1870 mg/l (7). These high levels of TDS or sulfates will make it difficult for releases from Devils Lake to meet water quality standards in the Sheyenne and Red Rivers. This of course makes people in the city of Devils Lake frustrated trying to solve their flooding issue and is of great concern to downstream interests that could receive the waters.

The other big issue that gets a lot of debate is the wetland drainage in the upper basin of Devils Lake. Agricultural interests say that the drainage is minimal and has no impacts on the flooding of Devils Lake. Many segments of the public and conservationists are concerned about the drainage and believe an upper basin storage program should be implemented to provide flood control along with water quality benefits, wildlife habitat, areas for recreation and tourism, and add to the economic diversity in the area.

Agencies that have been asked to quantify the data also disagree on the numbers. The range that has been discussed by N.D. State Water Commission and U.S. Fish and Wildlife Service technicians varies from 60,000 acres of drained wetlands with a storage capacity of 156,000-294,000 acre-feet, to 189,000 acres of drained wetlands, with a storage capacity of 491,000-926,100 acre-feet (3). The technicians could not agree on technique or parameters of the analysis so disagreement continues. The bottom line is that even if the minimum of 156,000 acre feet is available, that amount could prevent two feet of water from coming into the lake. There is also the possibility of storing additional water in upper basin lakes. The real fact of the matter is that upper basin residents are not extremely excited to restore wetlands. This is the main issue. The solution is to find programs that are fair to taxpayers, fair to landowners, and help address flood issues and watershed management in the Basin.

These two main issues, water quantity and quality, relate to all the controversy surrounding water management in the Devils Lake Basin. The recent drought followed by levels of water higher than current residents have ever seen has resulted in a cry for help. Local residents and government are asking State and Federal agencies to solve the fluctuating water levels. They are asking for drought protection for the recreational fishery, which yielded $33 million of gross business volume in the 1983-84 season (1), and flood protection for the city and surrounding lands from high water levels. Since the basin was settled, water issues have been on the forefront.

V. POTENTIAL SOLUTIONS

In the last several decades, agencies have evaluated several options for water management in the Devils Lake Basin. Ideas have included construction of an outlet, building an inlet, increasing water storage in upstream lakes, flood plain zoning, flood proofing buildings and infrastructure, controlling upstream drainage, obtaining flood insurance, restoring drained wetlands, building dikes and levees, evacuation, and implementing a basin-wide water management plan. All have merit and all have had problems. As with many issues in science the answer is usually not one simple answer.

The answer in fact is complex, and will more than likely be a combination of many of the previously mentioned actions. The considerations surrounding a solution are also complex. There are social and economic issues, biological and environmental issues, political and fiscal issues. Good science and engineering will be required to find the correct solutions.

The solution currently coming to the forefront is a three part solution consisting of 1) watershed management, 2) infrastructure protection, and 3) an outlet that considers the water quality and quantity issues of the Devils Lake Basin. Watershed management will include managing the upper basin lakes, restoring wetlands, controlling flows, managing runoff and addressing erosion, and implementing water quality practices known as "Best Management Practices", all outlined in a report entitled "The Devils Lake Basin Water Management Plan" (1). Infrastructure protection will include dikes, road raises, flood insurance, moving and evacuation of structures, and floodplain zoning (4). An outlet will include moving an amount of water out of Devils Lake that will not negatively affect the Sheyenne River or the residents that live next to the Sheyenne River or who utilize the waters for domestic use.

The final solution, whatever it may be, will involve scientific fact, engineering design, social issues with emotional overtones, and political intervention. Those scientists who are in the field working with decision makers will be asked to make choices and collaborate on solutions. This puts scientists in arenas where many are not comfortable, but essential to the future of the use of science in our political world. The Devils Lake Basin is truly dealing with troubled waters for citizens, scientists, engineers, and politicians. Hopefully, decisions will be made using facts and utilizing professionals to assist in beneficial outcomes for society.

References

1. Devils Lake Basin Water Management Plan (1995) prepared by Devils Lake Basin Task Force and the North Dakota State Water Commission
2. Stewart, R.B. (1975) Breeding Birds of North Dakota
3. Sapa, A.J. letter (1/31/97), Sprynczynatyk, D.A. and Sapa, A.J. letter (01/08/97)
4. Report of the Devils Lake Basin Interagency Task Force (1995) Federal Emergency Management Agency Region VIII
5. Wiche, G.J. (1996) Hydrologic and Water Quality Conditions in the Devils Lake Area, Preliminary Draft
6. Personal communication w/Mike Sauer, N.D. Dept. of Health 2/24/97
7. Devils Lake, North Dakota Contingency Plan (1996) U.S. Army Corps of Engineers

GEOLOGIC HISTORY OF THE DEVILS LAKE BASIN, ND

John R. Reid*[1] and John P. Bluemle[2]
[1]Department of Geology and Geological Engineering
University of North Dakota
Grand Forks, ND 58202-8358
[2]North Dakota Geological Survey
600 E. Boulevard Ave.
Bismarck, ND 58505-0840

Pre-glacial history

The Devils Lake Basin is the result of the continental glacier that covered the region during the late stages of the Wisconsinan ice advance. However, the conditions that allowed the excavation to occur formed long before. The pre-existing rocks set the stage for subsequent glacial erosion.

The oldest rocks beneath the basin are crystalline Precambrian rocks, more than 600 million years old. These ancient rocks are buried beneath one to four km of younger sedimentary rocks (1). Five sequences of these sedimentary rocks are recognized in the region, corresponding to five major inundations and retreats of near-tropical seas. The resulting sediments accumulated over a period of 500 million years. Although the sedimentary rocks that underlie the Devils Lake Basin are equivalent to those farther west in the more central part of the Williston Basin, they are thinner and, as yet, non-petroleum producing. The most common rocks are marine sandstones, limestones, and shales.

During the Cretaceous Period, 140 to 65 million years ago, the last seas inundated what is now North Dakota. It was during this time that the uppermost bedrock of the region was deposited, the Niobrara and Pierre Formations (shales). The Niobrara Formation is the uppermost rock unit only where the Pierre Formation has been eroded away, because the Niobrara Formation underlies the Pierre Formation elsewhere. Locally present are the Fox Hills and Hell Creek Formations (1).

The Niobrara Formation is a light gray calcareous shale; in the Devils Lake Basin it is between 100 and 120m thick. The overlying Pierre Formation is a darker marine shale which ranges in thickness from 70 to 390m. In places within the basin these formations are exposed at the surface; in other places the bedrock is buried beneath as much as 180m of Pleistocene and Holocene sediments. Because the Pierre shale is the uppermost rock unit in most of the basin, large quantities have been incorporated into the younger glacial sediments. Resulting sand and gravel deposits are therefore of poor quality for construction purposes. Of further relevance is the fact that both the Niobrara and Pierre shales are relatively impermeable, something that later determined the character of flow of the glacier ice over the region.

Glacial History

Earliest Glaciations. Very little is known about the early glacial history of North Dakota. Evidence indicates, however, that North Dakota was invaded several times by continental glaciers from the Hudson Bay ice center over the past 2 million years, the period called the Ice Age (2). Scattered boulders from the Canadian Shield region are interpreted as marking the farthest advance of an early glaciation. These lie south and west of the younger margins (3). As yet, these boulders have not been subjected to cosmogenic dating techniques to determine their time of deposition, and perhaps this is not possible due to spalling of their surface. Because the boulders are scattered and there is only one site where finer glacial sediment (till) has been observed (4), they must have been deposited before 70,000 yrs BP, perhaps more than 250,000 yrs BP. Two younger pre-Late Wisconsinan ice margins were mapped by Clayton, et al. (5), to the north and east of the region of scattered boulders. Within these margins the abundance of coarse clasts and patches of till is greater. It is estimated that more than 60m of surface erosion has occurred since the earliest glaciation in North Dakota (5). Significant thicknesses of tills are exposed along the east shores of Lake Sakakawea; the Medicine Hill Formation is probably pre-Wisconsinan in age (>70,000 yrs BP), whereas the Horseshoe Valley Formation may be early Wisconsinan (50,000 to 60,000 yrs BP)(6,7). The uppermost till, the Snow School Formation, was deposited by the Late Wisconsinan ice sheet, between 25,000 yrs BP and about 13,000 yrs BP. Thus far, the till units along Lake Sakakawea have not been traced into the Devils Lake region, but if the ice sheets extended into west-central North Dakota, they had to have advanced over the Devils Lake area, too.

Each time the ice sheets advanced into what is now North Dakota, the northward-flowing rivers were blocked by the ice. The evidence for the former direction of flow of all major rivers in this region lies in the existence and drainage patterns of buried channels (8). When these became blocked, proglacial lakes formed and drainage was diverted to the east and south. A major river channel once flowed north through the Devils Lake region (9). This, the ancestral Cannonball River system, deposited alluvium which forms part of the Spiritwood Aquifer today.

Latest Glaciation. The interstadial period following the Early Wisconsinan glaciation lasted from about 50,000 to 25,000 yrs BP, at which time the climate again cooled, causing the ice sheet to build up and advance southward for the last time (10). Most of the glaciated surface topography of North Dakota is the result of this event. The terminus of this ice sheet reached the Des Moines, Iowa, area about 20,000 yrs BP, but the westward limit in North Dakota reached only from the south-central border to the northwest corner of the State (3), well inside older glacial limits. From that time until the final melting of the ice sheet from North Dakota, about 11,500 yrs BP, the glacier fluctuated many times. Each readvance left ridges of glacial debris, some large, like the Edinburg Moraine, others more numerous but small, like the "washboard moraines" common in the Devils Lake region, perhaps a result of annual winter readvances during the recessional phases of the ice sheet (11). More important to the glacial history of the Devils Lake Basin is the subglacial thrusting that occurred.

The ice sheets that advanced over eastern North Dakota were unusually thin, perhaps less than 1km even when the terminus was in Iowa (12). This was affected by the underlying impermeable shale bedrock, wherever it occurred. Subglacial water, produced by the weight of the overlying ice (pressure-melting), allowed the glacier to slide faster even though thinner. Wherever the glacier advanced over more permeable sand and gravel deposits, either water pressure was reduced by more rapid drainage of the subglacial water into these deposits, or the pressure was increased by the addition of ground water in these deposits. Any reduction in pore water pressures at the base of the ice allowed for rapid deposition of basal tills. Any increase in pressure caused a decrease in strength of the subglacial material. This is what is believed to have occurred in the Devils Lake Basin. As the ice sheet advanced into the area, it encountered the partly buried Spiritwood Aquifer in which the hydraulic head was already high (Fig.1). As a result, even greater pressures developed toward the thinner terminus, to the south, severely weakening the subglacial units, i.e., the Pierre shale. Continued flow of the ice lifted large masses of this bedrock, transporting them until the ground water pressures were sufficiently reduced. The sudden discharge of the trapped ground water may have been responsible for eskers, frequently associated with such thrust blocks, or even mud volcanoes. When the glacier finally retreated from the region a large depression was left behind where the bedrock mass had been removed and, immediately downglacier, was the deposited block, including Sully's Hill (Fig.2) (13-15). Beds of disturbed (tilted, folded) shale can be found at numerous sites along the margin of that hill. A core through that hill shows interbedded shale and glacial sediments, attesting to the thrusting and stacking forces of the glacier.

Deglaciation. By about 12,500 yrs BP the ice terminus was retreating rapidly from North Dakota. Debris-veneered ice masses, insulated from rapid melting, were left behind as the active ice terminus retreated. Sully's Hill and the area all the way to the Sheyenne River had such buried ice which slowly melted under a variable thickness of debris. Large volumes of water also were released from the melting ice sheet. The water ran off the surface toward the front or became part of the internal drainage system of the glacier, discharging through subglacial tunnels. Where the land sloped toward the ice front, water became ponded as proglacial lakes. The chain of lakes associated with Devils Lake were of this type. Suspended silt and clay settled out of the lake water, especially in winter when the lakes froze over and currents were reduced. Where the land sloped away from the ice front, vast areas of sand and gravel were deposited by the overloaded braided stream channels, or the water drained directly via existing channels into the Sheyenne River or via the Heimdal Diversion Channel into the James River (16). Many of these channels are now abandoned.

It is important to understand that the topography to the south of Devils Lake, except for the thrust masses, is largely the result of collapse of glacial sediment upon melting of buried ice. This slow melting is believed to have taken place between 11,900 and 11,600 yrs BP (10). By then, most of the ice was gone from the area and the active ice front was far to the north of the present Canadian border. Left behind was an extensive area of lakes in the midst of collapsed topography. The Devils Lake complex probably was at its maximum level as the ice retreated from the region. The water certainly drained through tributary channels into the Sheyenne River, but may have also drained eastward through Stump Lake and out through the Tolna Coulee. The complicating factor in any interpretation is the fact that the entire area was still rebounding from deglaciation and the drainage elevations were significantly lower than today. Regardless, the lake level eventually fell below the elevation of the outlets and all subsequent fluctuations resulted from changes in the climate. Since cessation of outlet drainage, little change has occurred in the basin, except for climatically-induced fluctuations and the slow accumulation of sediments into the lake and the outlet areas.

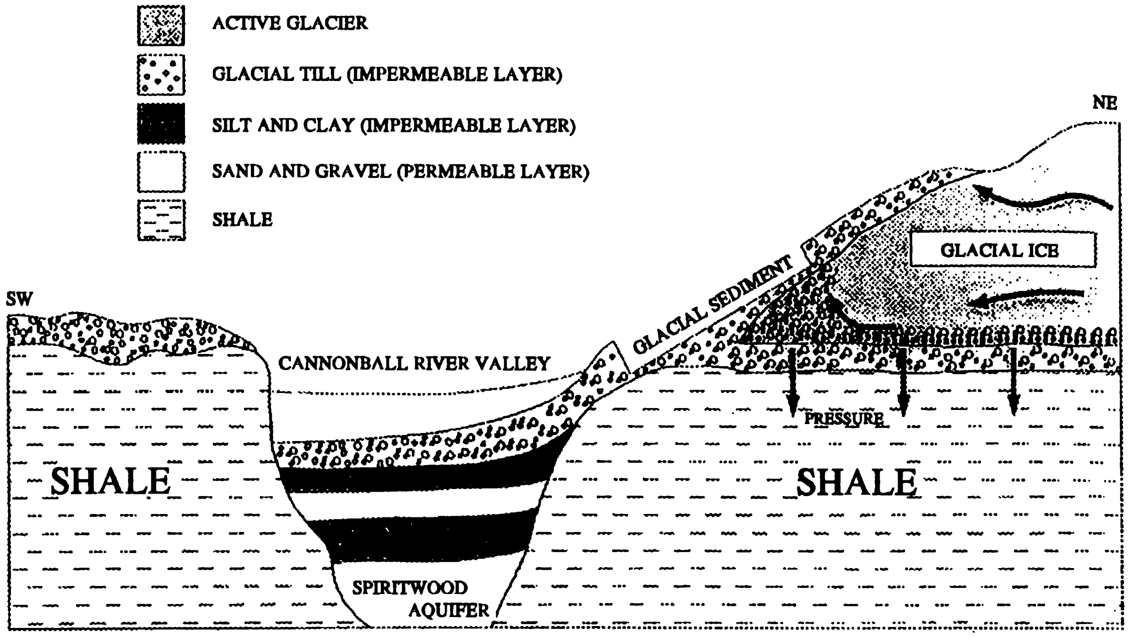


Figure 1. Advance of Ice Sheet into Cannonball River Valley.

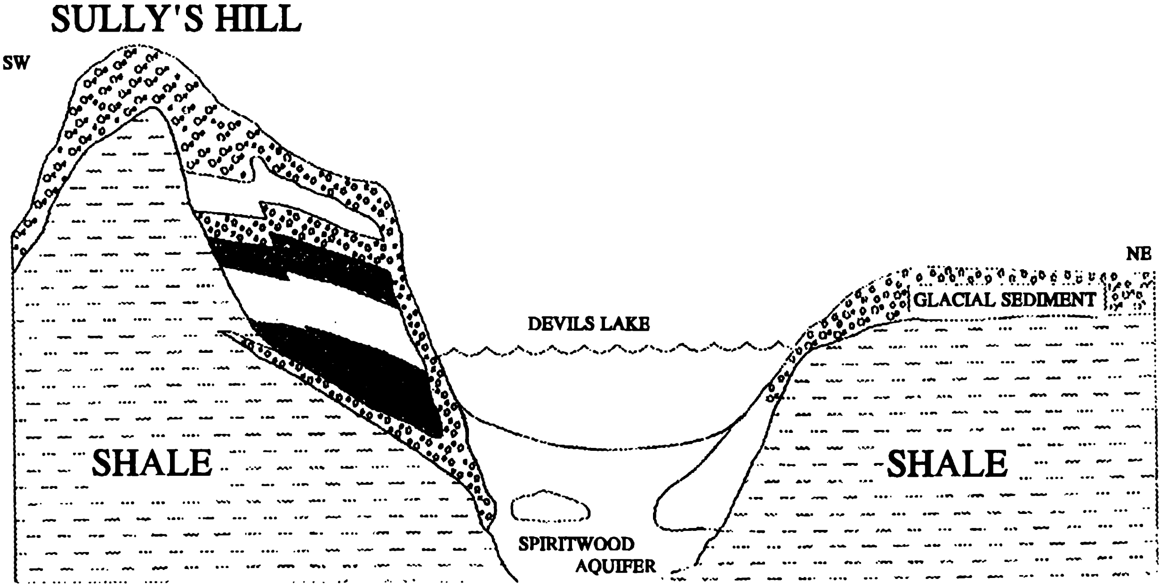


Figure 2. Result of Glacial Erosion, forming Devils Lake and Sully's Hill.

References

1. Carlson, C.G. and Freers, T.F., (1975) N D Geol Survey Bull. 59, Part I, 32p.
2. Harris, K.L. (1996) p.63-78 in N D Geol Survey Misc. Series 82, Harris, et al., eds. 165p.
3. Clayton, Lee (1980) Geologic Map of North Dakota: U S Geol Survey
4. Moran, S.R. et al. (1976) p.133-158, in Quaternary Stratigraphy of North America: Mahaney, W.C., ed., Dowden, Hutchinson, and Ross publ., Stroudsburg, PA,
5. Clayton, L. et al. (1980) N D Geol Survey Rept of Invest 69, 93p.
6. Beard, J.H. et al. (1982) Bull Amer Assoc Petroleum Geol, 66:2, p. 158-169
7. Ulmer, J.H. and Sackreiter, D.K. (1973) N D Geol Survey Rept of Invest 51, 1 sheet
8. Bluemle, J.P. (1972) Bull Geol Soc Amer, 83, p.2189-2194
9. Hobbs, H. And Bluemle, J.P. (1987) N D Geol. Survey Bull 71, pt.1, 69p.
10. Clayton, L. And Moran, S.R. (1982) Quat Sci Reviews, 1, p.55-82
11. Nielsen, D.N. (1969) unpub. Master's thesis, Univ North Dakota, 51p.
12. Brevik, E.C. (1994) unpub. Master's thesis, Univ North Dakota, 127p.
13. Bluemle, J.P. (1970) Geol Soc Amer Program Abstracts, Rocky Mt. Section, p.325
14. Bluemle, J.P. (1966) Proc N D Acad Science 20, p.112-118
15. Bluemle, J.P. and Clayton, L. (1984) Boreas, 13, p.278-299
16. Aronow, S. (1963) Bull Geol Soc Amer 74, p.859-874

SOILS AND STRAND LINES OF DEVILS LAKE, NORTH DAKOTA

J. L. Richardson* and C. L. Lura
Department of Soil Science, North Dakota State University, Fargo 58105
Biology Department, Minot State University-Botineau, Botineau 58318

INTRODUCTION

This paper is based on a report prepared for litigation on land ownership around Devils Lake (1). In the last 9000 years the lake elevations ranged from at least 1397 to 1453 feet (2,3). The lake levels are left in feet although all other measures are metric.

Soil formation results from the action of climate and living organisms, especially plants, acting on geologic materials, influenced by topography over time. The Devils Lake wave action resulting from water level fluctuation has altered four of these factors: geologic materials, topography, vegetation and time. Strand line as used here is the zone of beach and affiliated landforms that represent a shoreline for a period of time; a strand line usually can be traced around the edge of the lake basin. Shoreline is the water edge currently or at a specified time in the past. The wave action in a lake the size of Devils Lake alters sediments on the strand line by erosion and deposition because of the concentrated energy in the wave breaker area and rduced water energy levels in the quiet water off-shore. Exposed open areas are eroded, forming a distinct slope profile. Only coarse textured deposits (sands and gravels) remain on the erosion surface. These areas of the strand line are termed here as beach areas or beaches. The finer sediments are deposited off-shore from the beach. Protected areas in bays, such as Minnewaukan Flats, have flatter slope profiles. Depositional areas characterized by high clay are referred to as mudflats and only occur in quiet water with little wave action. The large distances of open water (fetch) allow for large waves to form. The large waves cause shoreline erosion, longshore, and off-shore sediment transport that segregates or sorts the sediments in a manner not typical of smaller lakes (3).

Active deposition or erosion terminates pedologic processes on preexisting soils which were either removed or buried. Subaerial soil profile development contrasts greatly from submerged soil development. Areas with fluctuating water levels have unique soil morphologic characteristics because alternate submergence and drainage is a distinct soil forming process. Therefore, a collection of young soils formed in four environments should exist in the strand line: Beach with soil series like Wamduska and Claire; near-shore sands Minnewaukan; near-shore to off-shore interstratified thin sand layers with loams soil series like Mauvais or Aquents in the Benson County Survey (4); and off-shore silty-clays like the Lallie series.

HYPOTHESIS: Shoreline fluctuations have created a wave cut topography at various elevations on the till surrounding the lake basin. The wave action removes the existing soil by erosion and "resets the clock" for soil development processes. Soils above certain strand lines will be distinctly older than those below. At some strand line it is expected that Entisols (young or recent soils) will occur below and Mollisols or Alfisols will occur above the strand line. Soil development and strand lines demonstrate age and stability of the shoreline around the lake basin.

METHODS

In the original study, six transects and multiple additional field observations of soils and vegetation were detailed (1). In this paper only two transects are described and observations on the soils from these transects are briefly mentioned. These two transects are very representive of the soils and the strand lines, however.

Soils and strand lines were studied along six transects (approximately from 1422 to 1445 feet elevation) on the major bays of the Devils Lake chain. The soils were examined by describing selected morphological features in the field and sampling for soil organic matter analysis (not reported here). The moist soil color was compared to a Munsell color chart in the field. Texture was field estimated. Soil survey information was also incoporated into the study even though only the Benson County Soil Survey was published at the time of the study (4). The soils mapped in the three county soil surveys differentiate Devils Lake and Stump Lake soils from the older Pleistocene lacustrine soils and wetland soils. The time interval between the Benson County Soil Survey (4) and the newer soil surveys was one with a lot of investigations on wetland soils that was reflected in the soil surveys conducted in Ramsey and Nelson Counties.

The use of mottles or redoximorphic features created by differential iron solubility under oxidizing and reducing conditions could not be used because the basin below 1453 feet had all been under water at least once. Nearly all these soils contain redoximorphic features, but the coloration often reflects relict conditions that have little meaning today. Also, certain mottle patterns appear to be created by sidehill seepage where water movement from the upland flows on the fine textured, that underlies coarse -textured sediments of the beach and near-shore lacustrine materials; these data are mentioned in the companion paper on vegetation as range site subirrigated. Flow patterns of this type were observed frequently. Therefore, we feel that redoximorphic features were too complicated for accurate interpretation. We only used redoximorphic features infrequently in our analysis.

FIELD INVESTIGATION

Graham Island Transect

The site is located in Sec. 27, T153N, R66W just south of the Old Military Reservation Boundary on the West Bay of Devils Lake. The lake escarpment in this locality is steep and is oriented northwest-southeast. A wave cut bench and a section of exposed sandy sediment extends from the wave undercut cliff for about 300 meters to the present shoreline. Some wind reworking and at least one storm beach can be seen from the wave undercut cliff to the present shoreline. The present land surface is grazed and does not appear to have been tilled or cropped.

Seven soil profiles were examined along a transect from about 200 meters offshore to the wave cut platform below the wave undercut cliff, or about 500 m total length. The shore profile is quite flat.

Submerged profiles (ZI1A at 20 meters from shore and ZI1B at 200 meters from shore) had about 7 cm of sedimentary peat (Lco-horizon) over sandy loam sediments to 40 cm and then dark colored silty-clay texture from there to 1 m (total depth examined). These young soils are highly subject to surficial wave erosion and receive longshore transported sediments.

The near-shoreline profile ZI1 was 8 m inland from the lake shoreline and about 30 cm above the lake when described and had about 3 cm of brown (10YR5/3) algal material above the mineral surface. From the mineral surface to 16 cm, we observed a black (10YR2/1) sand; next, from 16 to 40, a very dark gray (10YR3/1) sand occurred; below 40 cm the sands had depleted matric colors of grays (10YR5/1) with abundant prominent reddish (5YR4/6) accumulation zones. The mottles are of the type that indicate a history of recent and frequent water table fluctuations (5). The lake was about 1426 feet in elevation at the time we examined this site. An abrupt soil discontinuity existed between the shoreline profile and the two submerged profiles. Recent submergence or a different duration could cause the observed differences.

Profile (ZI2) was located 65 m inland from the shore at about 1430 feet elevation. The soil was a thin Entisol with a 0-7 cm A horizon overlying a 7-47 cm gray (10YR6/1) sand stratum with prominent reddish (5YR4/6) accumulations mostly concentrated near the bottom of the stratum. Below this stratum, a 40-58 cm buried A-horizon with a very dark grayish brown (10YR3/2) sandy loam was observed. Apparently, water moves laterally over the buried A because the gray overlying material contained such an abundance of reddish iron accumulations demonstrating reduction periods follwed by oxidizing conditions and some additions of iron. We believe that the iron was transported mostly by lateral flow. The two layer soil with the amount of red mottles indicates some stability. The profile is a variation of the Minnewaukan series.

Profile (ZI3) was located approximately 115 m inland on a low beach ridge at 1434 to 1435 feet elevation. The profile consisted of medium and coarse sands throughout the depth examined. The surface was 10 cm thick dark gray (10YR4/2) with another 5 cm of mixed A and C material below. The profile classifies as a Wamduska series. The soil is quite droughty and subject to blowing. The subsurface or C horizon was gray (10YR6/1) without accumulation zones, which indicates a lack of oxidized iron. We interpret this to mean that percolating water had removed iron. This area is a minor strand line.

Profile (ZI4) was located inland 55 m from ZI3 across an undulating but overall flat area at 1436 feet elevation. The soil consisted of stratified sands that varied from fine to medium sand in texture and lacked distinct horizons. The 7 cm thick A horizon was very dark grayish brown (10YR3/2), but below this the colors reflected stratification and ranged from 10YR4/3 to 10YR5/2. The C horizon here does not appear to have been subjected to water movement through the profile like ZI2 and ZI3 but we believe lateral flow occurred here.

The soil (ZI5) on the strand line at 1440 feet was located on steep wave-cut platform below a wave undercut cliff. The base of the upper wave undercut cliff and top strand line was located at 1454 feet elevation. The slope at the site was 6% and straight, not curved or concave like slopes cut from runoff erosion. The surface is covered with large, and often flat rocks and is interpreted as a gravel lag. The gravel lag resulted from wave erosion and armors the bench from further wave erosion. The thin soil (A horizon 7 cm and AC horizon another 7 cm thick) consisted mostly of gravel with some sandy loam material in the matrix between the coarse particles.

Above 1440 feet, at the wave undercut cliff, the land surface is much steeper but the soils have thick A-horizons, indicating older soils, and in this case the soils are like Towner series, a Mollisol. In this transect the three different strand lines of the lake are 1426 feet, 1434 feet, and 1440 feet and were all Entisols. The 1453-foot strand was present but not investigated. The Mollisols from 1440 feet and higher indicated stability for a substantial time. The lake, however, has not been that high for at least 115 years (6). At 1450 feet the upper wave cut levels occur. Levels below 1421 feet were not examined. The submerged areas contained soils that reflect the current submergence and were not useful in interpreting lake levels. Therefore, soils below 1421 feet would not likely be of much help.

When the Benson County Soil Survey was done (4), the shoreline was quite a distance lakeward from the shoreline at the time of our study. The mapped sequence of lacustrine soils illustrates the depositional energies of formation. Three soil series dominate the sequence. Lallie is the fine-textured offshore Entisol soil that often is a silty-clay. Lallie has three mapping units: the inner one is a marsh or very poorly drained lake remnant soil; the inner mapping unit is often ringed by a saline unit formed by capillary salt concentration; the last unit lies above the others and grades into sandier units. The first sand unit is the Minnewaukan series, which classifies as an Entisol. The third unit is the Claire (Wamduska) series that is better drained than the other two soils. The Claire soils form a ring around and above the Minnewaukan soils. This soil is an obvious beach soil. The Claire is present at 1434 feet and at 1440 feet; both are strand lines above 1443 feet, a Mollisol occurs, usually the Towner series. In some places the Bottineau soil, which is an Alfisol, occurs above 1440 feet in forested areas.

The mean high lake level, expected from pedological evidence, would be somewhere from the upper Claire to the Towner soils. The Lallie is sediment formed in the lake basin and the sandy soils are formed on the shoreline at the higher water levels or "mean" high water levels at that time. Over time these would be the shore, not the Lallie. The 1425 contour line on the Grahams Island and Minnewaukan East topographic maps occurs on Minnewaukan soils. Therefore, we believe that the soils distribution confine the last 300 years a mean high water level at between 1425 and 1440-feet in West Bay of Devils Lake. Above 1440 foot elevation, the existence of a Mollisol requires some age.

South Point on East Bay of Devils Lake

This site is located on the north side of the point in Sec. 19, T153N, R63W and overlooks East Bay of Devils Lake from the south. Also, the terrace above the transect which extended into Sec. 24, T153N, R64W was examined. This terrace is at 1442 feet, with several depressions lower than 1440 feet. Several prominent islands or peninsulas occur in and south of this terrace. This terrace is the equivalent height and comprised of sediments simila to the terrace east of Creel Bay examined in detail by Callender (3).

The terrace has Lallie soils and these soils occur above a large body of Claire soils and are associated with the wetlands on the terrace. These soils appear to have thicker A-horizons than the Lallie that is described in Strum et al. (4). Also on the terrace are Minnewaukan soils. One Minnewaukan delineation has two paleosols or buried soils that formed and were buried some time in the past. The deposition of sands and gravels was followed by water recession long enough to develop a well formed A-horizon. This A- horizon was then buried again. These buried horizons occur in a gravel pit at 1440 feet on the Devils Lake Quadrangle map. The buried soils indicate that at infrequent intervals, this whole terrace can be submerged, but most frequently it is above water.

From 1440 feet to 1426 feet, no beaches were observed. Below 1433 feet, the slopes are steep and soils are Entisols with a solid ground cover of vegetation. At 1430 feet, a modern wave-cut cliff of 1.5 m has only modern slump material or simply exposed terrace material without any soil development. The storm waves appear to be actively eroding this shore.

Profile ZII-1 at 1436 feet is on a flat lower portion of the terrace. From here the transect trends north on a steep, 15% convex slope to the top of the wave-cut cliff. This profile represents a stable terrace above 1434 feet. The soil has a 15 cm A-horizon of very dark grayish brown (10YR3/2) coarse sand. An AC-horizon of dark grayish brown (10YR4/2) sand extends to a depth of 30 cm. Below this, the material is only C-horizon. The soil color, as expected, indicates the soil is well drained. The terrace here does not appear to have been innudated for quite some time. The soil may have been exposed since about the time of European settlement in the area (1870's?).

Profiles ZII-3 and 4 were on the modern active beach (4) or in the active wave zone (3). These soils are simply wave eroded sediments lacking any horizons. The energy of the modern beach is causing significant retreat of the wave-cut cliff and reduction of the terrace.

Towner mapping Unit

The occurrence of the Towner series (Mollisol) mapping unit above the Minnewaukan (Entisol) unit at T153N, R65W on the Main Bay had been observed at Transect II. Towner was mapped above both a Claire (Wamduska) and Minnewaukan soil unit in Transect II on the terrace on the south side of East Bay. In order to study the relationship of Towner to the lower lying Entisols, the Towner mapping units were marked on soil maps (4). From these delineations of Towner soils, eight were selected for an elevation comparison. The type pedon for the Towner series for Ramsey County is located in Camp Grafton. The unit has Lallie (Entisol) below and Bottineau above. The Bottineau is a forest soil that has an argillic or well developed B-horizon and is the equivalent in terms of age and stability as the Towner. Delineation 1 on the Main Bay occurs just above the 1440 foot contour line or at approximately 1442 feet. Delineation 2 in Camp Grafton occurs on and above the 1440 foot line and below 1450 feet. Delineation 3 on the Main Bay is one mile west of delineation 1. This delineation extends from 1442 feet to the small wave-cut cliff at 1450 feet. Delineation 4 along Six Mile Bay falls below the 1445-foot contour only twice (1433 approximately) and lies below 1450 feet. Delineation 5 is mapped between 1440 and 1450 feet just east of the narrows between West Bay and Main Bay on the south side in Sec. 29, T153N, R65W. Delineation 6 lies above West Bay in Sec. 9 and 10, T152N, R66W. The unit lies above 1445 feet and crosses the 1450 foot contour slightly. Delineation 7 is near Transect II on the large point that juts into East Bay from the south. It lies between the 1440- and 1450-foot contour — by extrapolation, 1442 to 1448 feet. Delineation 8 is just west of delineation 7. The delineation starts at the 1440-foot contour and ends just below the 1450-foot contour.

From these data, we conclude that a distinct soil change consistently occurs at 1440 feet; the soil above 1440 feet has a thicker A-horizon. We have observed this along Six Mile Bay. The soil was 18 cm thick at 1440 feet and only 9 cm thick below 1438 feet. We also sampled an elm with 200 growth rings at 1446 feet (1). The Wamduska (Claire) soils have buried horizons at about this height, as observed on the terrace at Site II. Callender (3) extensively studied similar deposits with several buried soils on the east side of Creel Bay. He stated these end at 1440 feet, which he contended was stable for a considerable time period (at least before 1830). Aronow (2) also observed several deposits with buried soils. We also believe that the 1440 level is quite stable.

The strand lines at 1426 and 1434 feet had Entisols above and below the strands. Above 1440 feet Mollisolswere observed even though the higher soils were often steeper. Therefore the 1440-foot strand line represents a pedological age break.

References

1. Richardson, J. L., and Lura, C.L. (1986) Dep Soil Sci Res Rept No 19, NDSU, Fargo, ND.
2. Aronow, S. (1957) J Geol. 65:410-427.
3. Callender, E. (1969) PhD dissertation, Dep Geol, Univ. North Dakota. Grand Forks.
4. Strum, J.F.,Heidt, C. J., R.J.Bigler (1979) Soil Survey of Benson County. USDA, US Govt. Printing Off. Washington, DC
5. Richardson, J.L. and Daniels, R.B. (1993)pp 109-125 in Bigham, G. ed. Soil Color. SSSA Spec Publ no. 31 Madison, WI
6. Swenson, H.A. and Colby B.R. (1955) US Geol Surv Water-Supply Pap 1295.

VEGETATION IN THE STRAND ZONES OF DEVILS LAKE, NORTH DAKOTA

C. L. Lura*[1] and J. L. Richardson[2]
[1]Biology Department, Minot State University-Bottineau, Bottineau, 58318
[2]Department of Soil Science, North Dakota State University, Fargo, 58105

INTRODUCTION

Devils Lake is well known for its widely fluctuating water levels. Since the Pleistocene, lake levels have fallen from about 1453 feet elevation to about 1400 feet in 1940 (1). The water level has generally risen since. As a result of these as well as other conditions, the soil and vegetation have also been dynamic. The plant communities within the strand zones studied (approx. 1426 to 1440 feet) are a mosaic of forested shrub, as well as graminoid dominated associations. This paper will address the general relationships between soil and vegetation within the Devils Lake basin.

METHODS

Much of this paper is based on the work of Richardson and Lura (2). The study was conducted during autumn of 1985 to obtain information concerning soil and plant community development within the strand zones of the Devils Lake basin. The water level of Devils Lake at that time was 1426 feet. Six transects (approximately 1422 to 1440 feet) were subjectively selected on major bodies and bays of the basin. Soil and vegetation data were collected on each transect as well as at other locations within the basin (2). Vegetation along the transects was noted, and representative trees were cored with an increment bore to estimate age by ring counts.

FIELD INVESTIGATION

The Minnewaukan flats area is characterized by ponded soils (eg. Lallie and Parnell series). Above the shoreline, range sites classified as subirrigated (eg. Minnewaukan) are extensive. Because of the gradual slopes here, extensive areas of vegetation are expected to exhibit rapid change in response to water level fluctuations (3). Salinity is also a major factor influencing botanical composition (4).

The basin is characterized by Claire and Wamduska soils on strand zones with interstrand soils of Mauvais and Minnewaukan. These soils typically support a shrub dominated community consisting of woods rose (*Rosa woodsii*), western snowberry (*Symphoricarpos occidentalis*), and silverberry (*Elaegnus comutata*). Also common are scattered strands of aspen (*Populus tremuloides*), elm (*Ulmus americana*), ash (*Fraxinus pennsylvanica*), wild plum (*Prunus americana*), and chokecherry (*Prunus virginiana*) alone or in combination.

Management of these areas (or perhaps more accurately lack of active management) has been conducive to shrub invasion. Kentucky bluegrass (*Poa pratensis*) and other introduced cool season grasses along with leafy spurge (*Euphorbia podperae*) are also invading these sites. An evaluation of management, particularly on public land within the basin, may be appropriate.

Although aspen is found throughout the basin, it is of greatest importance in the Grahams Island area and around the Creel Bay and the Camp Grafton area, particularly on soils of the Bottineau series (fine-loamy, mixed Udic Argiboroll). The Bottineau soils occur in the Devils Lake basin above about 1440 feet. Argiborolls are formed under forest, and typify the soils of the Turtle Mountain aspen forest of North Dakota and Manitoba. Common associates of these stands in separate or mixed communities are bur oak (*Quercus macrocarpa*), ash, elm, and boxelder (*Acer negundo*).

Tree coring data are summarized in Table 1. Trees were frequently observed below 1426 feet, however, and those that were observed, were dead and within approximately 3 feet of water. Obviously conditions above 1426 have been more stable in recent history and thus more conducive to tree establishment. Cottonwood (*Populus deltoides*) and aspen were commonly encountered, with a trend toward increased age with elevation. We did not encounter American elm, however, below 1430 feet, and bur oak and basswood (*Tilia americana*) were not encountered below 1438 feet. It should be noted that several large American elm were observed between 1455-1450 feet in Sully's Hill Game Preserve. These trees had been cut during 1983 due to infestation of Dutch elm disease. Although heart rot of these trees precluded precise aging, we estimated several at the site to be at least 200 years old.

Table 1. Mean age of cored trees by elevation (in feet) for the Devils Lake Basin, 1985 (2).

Species	Elevation						
	1426	1427	1428	1430	1431	1432	1438-46
Populus deltoides		44.0	58.0	48.0	52.0	47.3	
Populus tremuloides	19.6*	23.7	21.0	23.6		29.3	
Fraxinus pennsylvanica		52.0*	44.0	24.0	50.0		
Ulmus americana				58.0			200.0
Quercus americana							51.0
Tilia americana							47.0

* Dead at time of sampling.

Edaphic as well as other factors would seem conducive to greater establishment of trees than observed in the basin. A number of factors may, however, reduce the ability for trees to become established near the shoreline. These factors likely include ice thrusting. Ice thrusting may be a principle factor preventing the establishment of trees in many nearshoreline locations. Ice thrusting can disrupt and transport large amounts of the shoreline substrate. The vertical height of shoreline affected can be greater than 3 feet (5). Conditions were observed that are consistent with ice thrusting, and personal communications with local residents confirm that ice thrusting is common. As a result, graminoids and other herbaceous vegetation may be quicker to establish. When conditions do become more conducive to tree establishment, interspecific competition may limit their establishment.

Water of the Devils Lake chain increases in salinity from the Big Coulee inlet to East Stump Lake (6). The influence of salts on vegetation are, as a result, more common and pronounced in the east end of the chain. Open water spray and salt blown from the open or exposed salt flats such as those that occur around East Stump Lake may significantly influence vegetation (7). These influences, coupled with soils such as Lallie-saline phase, may be the major factors influencing community composition here. Range site designation for much of this area saline lowland, characterized by halophytic plants such as inland saltgrass (*Distichlis spicata*), foxtail barley (*Hordeum jubatum*), goosefoot (*Chenopodium spp.*), as well as saltwort (*Salicornia rubra*) on the more saline sites. As distance from the shoreline and elevation increases, vegetation typically becomes a mosaic of aspen stands interspersed in dense woods rose and other shrubs.

References

1. Aranow, S. (1957) J Geol. 65:410-427.
2. Richardson, J. L., and Lura, C. L. (1986) Dep Soil Sci Res Rept No 19, NDSU, Fargo, ND.
3. Harris, S. W., and Marshall, W. H. (1963) Ecology 44:331-343.
4. Stewart, R. E., and Kantrud, H. A. (1972) Geol Surv Prof Pap 585-D.
5. Ruhe, R. V. (1975) Geomorphology. Houghton Mifflin, Boston, MA.
6. Swenson, H. A., and Colby, B. R. (1955) U. S. Geol. Surv. Water-Supply Pap. 1295.
7. King, C. A. M. (1972) Beaches and Coasts, St. Martins Press, N.Y., NY.

ARCHAEOLOGICAL STUDIES IN THE DEVILS LAKE BASIN

Fred Schneider* and Dennis Toom
Department of Anthropology, University of North Dakota, Grand Forks, ND 58202

INTRODUCTION

The Devils Lake Basin has received the attention of archaeologists since the late 1800s. In fact, some of the earliest archaeological studies in the state were conducted in this region (1, 2). Unfortunately, many early investigators poorly documented their research so that today there are problems in determining the locations of the archaeological sites reported and/or excavated by these pioneering archaeologists. Since those early days, the region has received sporadic attention from archaeologists. Most efforts have surrounded preliminary surveys in anticipation of the Garrison Diversion Project, the development of new U.S. Fish and Wildlife facilities at Sulley's Hill National Game Preserve, the development of Graham's Island State Park, and most recently, the preparation of archaeological impact assessments of road improvements related to the flooding of the lake basin. The result has been that the lake basin as a geographic unit has never been the focus of a systematic archaeological assessment program. Most archaeological studies and most archaeological attention have focused on areas adjacent to Devils Lake with little work in the northern portions of the basin. Archaeological projects have been on an as-need basis resulting in archaeological investigations of differing levels of magnitude, of differing levels and requirements of reporting, and distributed in a non-systematic nature throughout the basin. Generally, few archaeological excavations have been conducted--the majority of archaeological work has been in the nature of preliminary assessments consisting of pedestrian field surveys and occasional use of limited auger probes or test excavations.

Despite the above there has developed some baseline information about the prehistoric cultural resources and the prehistoric occupation of this region of the state. The following provides a brief overview of this prehistoric record as it is documented in the DL Basin.

PaleoIndian

The first prehistoric peoples of the state, the PaleoIndians, are yet to be documented in the basin. These people resided elsewhere in the state from circa 10,000 to 7000 BP, were hunters of extinct species of bison and other large game animals, and were the first to quarry and trade Knife River flint. Archaeological evidence for these peoples and their cultures is primarily documented in western ND with a few artifacts reported from the eastern portion of the state. PaleoIndian projectile points are reported from a locality immediately south of Devils Lake along the Sheyenne River Valley (3) and from Bottineau County northwest of the Devils Lake Basin (4). It is assumed that more artifacts and archaeological sites of this first period of human presence in the state will be found in eastern North Dakota and in portions of the Devils Lake Basin. However, it is also assumed that the density of these materials will be considerably less than that of the western two-thirds of the state (5). In addition, it is anticipated that these yet to be identified PaleoIndian sites in eastern North Dakota will relate primarily to the later part of the period given what is known about terminal Pleistocene conditions in the region. In the Devils Lake Basin these late PaleoIndian artifacts will most likely be associated with topographic high areas adjacent to large, permanent water sources which were present from circa 10,000 to 7000 BP.

Plains Archaic

The succeeding Plains Archaic cultural period dates from circa 7000 to 2500 BP. A distinguishing feature of this cultural period is the appearance of side-notched projectile points, the greater use of groundstone tool technology, intensive plant collecting, and, early in the period, the hunting of an extinct species of bison, *Bison occidentalis*. Much of this cultural period is associated with marked fluctuations in climate and extended periods of aridity, events known as the hypsithermal or altithermal. The Archaic period is associated with the expansion of grasslands to the north and east of the Plains. The Archaic is divided into three cultural-chronological units. The Early Archaic (7000 to 5000 BP) is associated with the Logan Creek/Mummy Cave complex and the Oxbow complex. The earliest documented human presence in the Devils Lake Basin is the Oxbow complex in the form of Oxbow projectile points identified at the Irvin Nelson site (6), located along the south shore of Devils Lake. The Oxbow complex is dated elsewhere from 5500 to 3000 BP, overlapping with Middle Plains Archaic. Oxbow points have been reported from throughout much of the state. The Middle Archaic is associated mainly with the McKean complex which dates from 5000 to 3000 BP. McKean complex artifacts have been observed and recorded in collections from throughout the state, and have been recovered from the Irvin Nelson site, as well. The Late

Archaic, best known from the Pelican Lake complex, is dated to 3600 to 2100 BP. Artifacts of this complex are also noted at the Irvin Nelson site as well as at sites throughout the state. It is strongly suspected that additional sites and artifacts of the Archaic Period complexes will be found elsewhere in the Devils Lake Basin, and that many of these sites may also be located along former shorelines of the lakes within the basin.

The Irvin Nelson site (32BE208), on the south shore of Devils Lake, is located in the headquarters compound at the Sulley's Hill National Game Preserve. The site ranges in surface elevation from 1450 to 1458 feet above mean sea level (amsl), at or just above the highest level of Devils Lake. The Archaic period occupation of the site is reported to be covered by what the investigator identified as "wave-action deposited littoral sand"(7). Radiocarbon dates from this lower cultural zone are 2860±70 BP, 1820±170 BP and 1160±60 BP. Unfortunately, there are serious geological and archaeological interpretative problems with this site. Excavation notes, stratigraphic profiles, artifact, and radiocarbon sample provenience data are poorly documented and it is impossible to clearly determine the association of particular strata, artifacts, and radiocarbon dates. This is unfortunate for the site covers a broad area spanning elevations relating to early lake levels. It is impossible to determine whether particular artifacts and/or radiocarbon dates are from below or above the elevation of the high lake level. The earliest radiocarbon date would be appropriate for dating the Late Archaic (Pelican Lake) component at this site.

Plains Woodland

The next cultural period, Plains Woodland, dates from circa 2200 to 1000 BP, and is linked to the appearance of pottery, earthen burial mounds, and in its last phases, the bow and arrow. The majority of the archaeological sites recorded in the Devils Lake basin are of this cultural period. The earthen burial mounds have attracted the attention of archaeologists and others since the last century and have been the focus of many past investigations. Unfortunately, the record of this work is frequently lacking information as to the location of excavation and the description of the structure and content of these mounds. The excavations at the Irvin Nelson site also recovered artifacts associated with the Woodland Period. Specifically, artifacts were recovered from Middle and Late Woodland cultural complexes, including Besant and Avonlea projectile points and Laurel-like and Sandy Lake ceramics. Two radiocarbon dates from this site would appear to be associated with the Middle Woodland occupation (1820±170 BP and 1340±120 BP).

Early, Middle, and Late Plains Woodland occupations are reported for the Horner-Kane site (32RY77) in Graham's Island State Park (8, 9). The site is located on the southeast end of the island, and ranges in elevation from 1454 to 1477 feet amsl. The main Woodland occupations at Horner-Kane are located in the higher elevation parts of the site, above the highest wave-cut bench on Devils Lake which is at an elevation of about 1450 feet amsl. Organic residue from a Laurel-type rim sherd from Horner-Kane yielded a radiocarbon age of 1140±50 BP, and organic residue from a Middle Woodland body sherd produced a radiocarbon age of 1910±50 BP. The Laurel rim date falls within the Late Woodland period, which is consistent with the presence of Black Duck pottery in the assemblage.

It is remarkable that Middle Woodland pottery from the lower elevation part of the Horner-Kane site appears to have been eroded by wave-action. The cultural deposits here are in a sandy loam developed from beach deposits composed mainly of sand and gravel. Whether these eroded and rounded pottery sherds indicate that lake levels rose after the Woodland occupation of the site, whether post-Woodland occupation wave-action has eroded the shoreline exposing a previously buried Woodland occupation, or whether that the Woodland occupation was directly on the shoreline of the lake is not understood. Also of interest is the fact that later, post-Woodland occupation artifacts in this area have not been subject to the same kind of erosive forces, suggesting a post-Middle Woodland lowering of lake levels.

Late Woodland occupations are present at the Irvin Nelson site, the Horner-Kane site, and at the Sharbono site (32BE419). A radiocarbon date from the Irvin Nelson site of 1160±60 BP could date the Late Woodland occupation of the site. The Sharbono site is situated on the southwestern portion of Graham's Island at an elevation of 1450 amsl (10). The Late Woodland occupation at Sharbono is minor in comparison to its later Plains Village occupation.

Another excavated site in the region is a large mortuary complex southeast of and overlooking Sweetwater Lake (11). 32RY100 was a prehistoric cemetery disturbed by gravel quarrying. The site is on a small hillock at elevations ranging from 1450-1510 feet amsl. The remains of 30 individuals were found in seven graves. There was no evidence of an earthen mound over the graves and few artifacts were found in association with these individuals. A single radiocarbon date was obtained from the organic matrix of one grave pit and provided an age of 1140±110 BP. It is not certain as to precisely which cultural period and complex these burials relate to. The nature of the interments themselves and the associated radiocarbon age point to a Late Woodland affiliation. Nevertheless, an early Plains Village affiliation is not beyond reason. Unfortunately, a bulldozer had disturbed much of the site integrity and, possibly, greatly obscured the cultural identity of this site.

Plains Village

The Sharbono site is also noted for the presence of pottery from the next major cultural period, the Plains Village period. This period begins approximately at 1000 BP and lasts through the time of early historic White contact. In North Dakota, Plains Village culture was centered in the Missouri River valley, well to the southwest of Devils Lake. However, a significant Plains Village presence has been identified in eastern North Dakota, including the Devils Lake area (12). The hallmarks of Plains Village culture are a semisedentary settlement pattern, characterized by use of permanent earthlodge villages, some of which were fortified, and a mixed subsistence strategy based on horticulture, or garden agriculture, as well as hunting and gathering. Distinctive forms of pottery are also associated with Plains Village.

The Sharbono site is identified as having an occupation of this cultural period on the basis of its ceramic collection. Most of this occupation is associated with a dark, sandy loam which has developed from coarse beach sands. It is of interest that there is supposed to be a village of the Hidatsa on Graham's Island, a village occupied prior to their move to the Missouri River valley (13). The Plains Village pottery at the Sharbono site may represent the former use of this locale by the Hidatsa and/or other Plains Village peoples. Plains Village pottery at the Irvin Nelson site is most likely associated with a radiocarbon date of 400±100 BP. Plains Village pottery was also found at the Horner-Kane site. Organic residue from a Sandy Lake-type rim from Horner-Kane produced a radiocarbon age of 740±50 BP, and organic residue from a Buchanan-type rim gave a radiocarbon age of 730+50 BP. Buchanan ware is directly linked to Plains Village, whereas Sandy Lake is generally thought of as Late or even terminal Woodland. The types do co-occur with considerable regularity, indicating a blending of Plains Village and Plains Woodland traits in the Devils Lake region and elsewhere in eastern North Dakota. A protohistoric, or late Plains Village, occupation also has been identified in the lower elevation part of the Horner-Kane site on the basis of its ceramic content and an associated radiocarbon ages of 250±40 and 290±40 BP (14).

Changing Lake Levels and Archeological Periods

The prehistoric human presence in the Devils Lake Basin was one which was affected by past changes in lake levels and changes in the resource base within and surrounding the basin. Extended periods of drought would clearly have affected lake levels, water potability, availability of aquatic resources, and the variety and numbers of potential mammalian food resources. Extended droughts also would have been at the expense of forest resources needed for protection, construction materials, and fuel. Gregg (15) has speculated that prehistoric human occupation of the Devils Lake Basin was greatest when lake levels were high, insuring a viable resource base. In this regard, it is remarkable, but not surprising, that all recorded habitation sites around Devils Lake occur above 1450 feet amsl, the approximate level of the highest wave-cut bench surrounding the lake, and also approximately the highest possible lake level before it would drain naturally into the Sheyenne River via Stump Lake. But, it is not surprising that all prehistoric habitation sites are above 1450 feet around Devils Lake because maximum lake levels that have occurred in the recent past would have completely obliterated any lower elevation sites.

Callender (16) indicates that Devils Lake fluctuated throughout its 10,000 year history, and that there were marked periods of high and low water. Bluemle (17) reports the presence of buried soils beneath beach deposits along the north shore of the lake. These are interpreted as marking episodes of stability in the lake, punctuated by increased lake levels with overflow to Stump Lake and the Sheyenne River beyond during high water episodes in the basin (18). Four of these episodes of soil formation are dated between 3000 to 1500 BP, and a fifth dates to about 800 BP. Combining this information with what is known about post-Altithermal prehistoric human occupation around Devils Lake, the suggestion is made that high lake levels were present, at one time or another, during all major cultural periods from Plains Archaic (Oxbow) through Plains Village. We do not, however, have sufficient information at this time to determine whether or not the area was essentially uninhabited during episodes of low lake levels. Additional site investigations and many more radiocarbon dated components would be necessary to make such a determination. Nevertheless, this finding is significant because it raises the clear possibility of using archaeological data to better understand the dynamics of the Devils Lake system.

CONCLUSIONS

The above is a brief account of the sites that have been excavated in the Devils Lake Basin and, based on this information, what we know about the prehistoric past of the area. Numerous other sites have been located and recorded, and most not being the focus of text excavations or site excavations are poorly understood as to their cultural identity. The Devils Lake Basin has always been a dynamic system, one which has affected humans and their use of this region throughout prehistoric time. One would assume that this region was a valued area for prehistoric peoples as regards its availability of water, shelter, fuel, and varied food resources.

The presence of numerous earthen burial mounds located generally on high points around Devils Lake speaks to the presence of Woodland and perhaps early Plains Village peoples in the region. It is expected that future archaeological surveys and excavations will reveal greater indications of the presence of sites and artifacts of these peoples than that presently recorded. One should also expect additional finds of Plains Archaic sites. It appears that archaeologists would be advised to concentrate their search for evidence for these peoples in localities adjacent to current lakes and at elevations above 1450 feet amsl. Those areas offering some protection from prevailing westerly winds, adjacent to timber for fuel, and offering a variety of potential plants for foods, medicines, and raw materials would be most likely highly favored by prehistoric occupants of the region.

While the above has focused on prehistoric cultural resources of the basin, one should not overlook the significance of historic European American and Native American use of the region and the presence of numerous historic archaeological sites and structures that relate to the Devils Lake Sioux Reservation, the military presence at Fort Totten, the fur trade, pioneer homesteads, the cities of Devils Lake and Minnewauken as well as many other small towns of the region, several short-lived speculative railroad communities, structures related to railroad history, and highway bridges. This is a region rich in many cultural resources which have contributed to the development and history not only of the Devils Lake Basin but of the state of North Dakota as a whole. The survey, inventory, and evaluation of these historic resources suffer from many of the same problems as do those of the prehistoric period. Our knowledge of the human presence and use of this region is poorly developed at best, but there is great potential through the study of prehistoric and cultural resources to contribute substantially toward our understanding of the past and to better comprehend how our present world and lives came into existence.

In closing, we can note once again that high water levels in Devils Lake are nothing new, and the up and down cycle of the lake will certainly be a significant factor in the human occupation of the area in the future. Prehistoric peoples appear to have adapted to this environmental variable by occupying the high ground. We would suggest that such a solution to the current Devils Lake problem may not yet be outdated.

References

1. Montgomery, H. (1889) Proc Amer Assoc Adv Sci 38, pp 342-344.
2. Montgomery, H. (1906) American Anthropoloist 8(4), pp 640-651.
3. Schneider, F. (1982) Manitoba Archaeological Quarterly 6, pp 16-43.
4. Miller, W. (1992) A Survey and Analysis of Surface Collected Paleo-Indian Points from Bottineau County, ND. Honors Thesis submitted to Univ. ND for a BA degree.
5. Schneider, F. (1982) Manitoba Archaeological Quarterly 6, pp 16-43.
6. Fox, S. (1982) Excavations at the Irvin Nelson Site, 32BE208. Report submitted to U.S. Fish and Wildlife Service, Denver, CO.
7. Fox, S. (1982) Excavations at the Irvin Nelson Site, pp 9, 22.
8. Gregg, M. (1994) Horner-Kane Site (32RY77) Archeological Excavations, Grahams Island State Park, Ramsey County, North Dakota, 1991 Field Season. Report submitted to U.S. Bureau of Reclamation.
9. Toom, D. (1997) Horner-Kane Site (32RY77) Archeological Excavations at Grahams Island State Park, ND. Report to be submitted to U.S. Bureau of Reclamation.
10. Schneider, F. (1988) Sharbono Site Test Excavations: 1986. Report on file in Dept. Anthropology, UND.
11. Dill, C. (1984) The Devils Lake Burials: An Evaluation of Site 32RY100. Report on file in State Historical Society of North Dakota.
12. Schneider, F. (1986) The Devils lake Basin Archaeological Sites and Interpretation. Report submitted to ND State Attorney General's Office, Bismarck, ND.
13. Will, G. (1924) Anthro Papers Amer Museum Nat Hist 22(6), pp 285-344.
14. Gregg, M. (1994) Horner-Kane Site, pp 4.24.
15. Gregg, M. (1994) Horner-Kane Site, pp 14.9.
16. Callender, E. (1968) The Post-Glacial Sedimentology of Devils Lake, North Dakota. Thesis submitted to the Univ. North Dakota for a PhD degree.
17. Bluemle, J. (1991) Radiocarbon Dating of Beaches and Outlets of Devils Lake. ND Geological Survey Miscellaneous Series 75.
18. Gregg, M. (1994) Horner-Kane Site, pp 2.3.

THE DEVILS LAKE FISHERY HISTORICAL, CURRENT AND FUTURE PERSPECTIVES

Terry R. Steinwand*
North Dakota Game and Fish Department
100 North Bismarck Expressway
Bismarck, ND 58501

INTRODUCTION

Devils Lake is rich in history and lore. The area has also been one of controversy whether water levels are low, as in 1991, or high, as at the present time. This paper is a compilation of historical and current information regarding the fishery of Devils Lake as well as a future perspective.

The fishery of Devils Lake has been an extremely valuable resource, which is primarily a function of the excellent sport fishery that has resulted during adequate water conditions. The lake has historically exhibited water level fluctuations which led to a tremendous fishery but has also the been the cause for their demise.

HISTORICAL PERSPECTIVE

Historical references to the fishery of Devils Lake is somewhat limited and much is anecdotal in nature. The earliest references to the fishery of Devils Lake were by Lord (1), Woolman (2), and Pope (3) but is limited in scope. Devils Lake has always experienced water level fluctuations and the fishery has consistently followed those fluctuations. The Devils Lake area has often been described as one of little or scanty rainfall (2, 3, 4). These observations were undoubtedly made at a time when Devils Lake elevations were declining rather that increasing as they have in the period from 1993 through 1997. Northern pike (*Esox lucius*) were not abundant in an 1892 survey but there is anecdotal evidence that pike (referenced as pickerel in the report) were the most abundant species (2). A winter fishery was evidently present prior to that time since pike were taken with hook and line during the winter season in great numbers, piled up and sold literally by the cord. Brook stickleback (*Culaea inconstans*) were evidently doing well at that time and actually increasing in number.

Pike disappeared around 1889 (2, 3) and no game fish species were found to be present until documented human intervention in the middle of the 20th century. Historical survey methods, however, are suspect since only seines and small traps were used, which are not conducive for the capture of adult northern pike. Prior to 1889 Devils Lake was allegedly "teeming" with pickerel. The average fish weighed between 5 and 6 pounds (2.27 to 2.72 kg) with a number of 17 or 18 pound (7.72 to 8.17 kg) fish being caught (3). One specimen allegedly weighed 19 pounds (8.63 kg). The average length of these fish was 2 feet (610 mm) with the largest measuring 3 feet (914 mm). Using present day data (5), a 5 or 6 pound northern pike should measure between 27 and 29½ inches (686 and 750 mm, respectively). Using a maximum length of 36 inches as reported (3), the pike would weigh about 10½ pounds (4.76 kg), which is significantly less than reported. Evidently fish stories haven't changed much throughout the years.

Pike under seven inches(178 mm) were rarely seen or caught during this time frame, which may be an indication of inconsistent or nonexistent natural reproduction. This is speculation at best since young-of-the-year northern pike are not normally caught by hook and line nor are they readily speared. They also do not normally participate in the spawning migration nor associate with the larger fish.

Creel Bay was evidently the principal fishing ground prior to 1889, which at that time touched the city of Devils Lake but at the time of the survey in 1907 was as 1.5 miles from the city (3). The greatest abundance of pike appeared to be from 1884 through 1887 during which time the "narrows" of Creel Bay, which is approximately where the lagoon dike currently exists, was a popular spot. The pike migrated through this area during spawning and were speared by the thousands. According to reports, a U.S. agent at Fort Totten purchased 2 carloads at one time and the Devils Lake butcher had a standing order for 1,200 pounds daily. There was no attempt to protect the fish from over-harvest or sustain the population.

The historic origin of northern pike is speculative but they may have been stocked by local immigrants as the abundance of pike has been associated with the influx of Scandanavians to the Devils Lake area. A more plausible explanation is movement through the Rock Lake drainage during periods of high flow such as that seen in the mid 1800's. This is based on recent information that recorded the common carp (*Cyprinus carpio*) in Rock Lake during the summer of 1995. Local contacts also note that northern pike are often seen in these drainages during spring runoff (6) even though the lakes in these areas of North Dakota are subject to winter kill. They have been unable to move through Mauvais Coulee because of a railroad grade currently acting as a barrier. It's believed that this obstruction was not in place prior to the 1860's and pike could have had several years of colonization in Devils Lake via this route.

The major loss of pike evidently occurred during the winter of 1887-88. One document (3) reports that "pickerel were discovered by the wagon loads, dead along the shores and sloughs at the south end of Dry Lake." Apparently they acted similar to that of the present time, i.e., migrate upstream during spawning and remain in those areas if favorable conditions and adequate food supplies are present. Often times they become trapped and ultimately succumb to winterkill conditions, which appears to be a major factor in the die off of 1887-88.

There is speculation on reasons for the disappearance of northern pike from Devils Lake (3, 7). Over fishing and destructive fishing methods, the "corrosive" effect of lake water, loss of spawning grounds, absorption of moisture by plowed lands and even the possibility of underground outlets to the lake, are some explanations that have been offered. Most are logical and it's likely that a combination of the factors led to the extirpation of northern pike from Devils Lake, with the exception of the underground outlets. Salinities can be somewhat discounted as a major causative factor in the drastic decline since acclimatization experiments were also performed using northern pike, white sucker (*Catostomus commersoni*), bullhead (*Ameirus nebulosus*), yellow perch (*Perca flavescens*), and largemouth bass (*Micropterus salmoides*) (3). Samples of these fish were held in cages for times ranging from 4 to 75 days with little mortality experienced. Based on these experiments it was concluded that these species were not affected by the lake's current water quality. It appears that TDS levels at that time were approximately 9,500 ppm. This is higher that what is currently present but lower than recent concentrations during which time fish survival still occurred. That fish were still present in the early 1900's is evidenced from the capture of sticklebacks in the Mission Bay area. In addition, "minnows with nuptial tubercles", presumably male fathead minnows (*Pimephales promelas*), were also found.

The period that followed the dramatic loss of the fishery, circa 1889 through 1955, has sparse information on the fishery resource. Information reiterates what had previously been reported on the fishery of the lake (7). High BOD's and salinities likely made it a highly inhospitable environment for most fish species other than brook stickleback and fathead minnows.

CURRENT FISHERY

Rising water levels in the mid-1950's renewed interest in establishing a sport fishery in Devils Lake. A cursory survey of the lake in May 1955 by the North Dakota Game and Fish Department revealed nothing for sport fish, with only one white sucker being captured in West Bay, which indicated some fish survival during the previous winter. Heavy spring flows in 1956 and lake levels rising to 1416 feet msl prompted the North Dakota Game and Fish Department to experimentally stock 50,000 northern pike fingerling into Devils Lake from the Valley City National Fish Hatchery (8). A subsequent survey in September of 1956 found that northern pike survived and exhibited fairly good growth. As a result of this survival further introduction of northern pike occurred again in 1957 and 1958. An excellent fishery in 1958 allegedly resulted from these two fish introductions. Surveys in the fall of 1958 indicated over-winter survival had occurred and a fair population of northern pike had become established. Pike as large as 24.5 inches (622 mm) were found, with fish at least 2 years old, which provides further evidence that survival over-winter had occurred. Although survival was noted, water levels were once again declining and it was felt that the present water levels of Devils Lake would not allow survival during the winter of 1958-59. It was recommended that no further stocking of northern pike occur until such time that lake levels return to the 1955 levels, which was approximately 1415 feet msl (9). A severe winter kill occurred during the winter of 1958-59 and surveys in 1959 indicated minimal survival occurred (10). Stocking or surveys were not performed from 1960 through 1966.

The dynamic nature of Devils Lake once again surfaced, with water levels partially returning to approximately 1412 feet msl in 1966. A survey found only brook stickleback and fathead minnows, but a decision was made to once again attempt to establish a sport fishery based on rising water levels. In May 1967, 26,250 northern pike fingerling were introduced from the Garrison Dam National Fish Hatchery. Water levels were considered marginal but the rising hydrograph indicated that survival was likely. This planting, in association with subsequent northern pike stockings, survived and was ultimately the beginning of the modern day recreational fishery of Devils Lake.

The present day fishery is a result of North Dakota Game and Fish Department's effort to provide a variety of fishing opportunities. Other species, in addition to northern pike, have been stocked. The species stocked from 1969 to the present were walleye (*Stizostedion vitreum*), yellow perch (*Perca flavescens*), white bass (*Morone chrysops*), crappie (*Pomoxis* spp.), muskellunge (*Esox masquinongy*), striped bass (*Morone saxatilis*), and tiger muskie (*E. lucius* X *E. masquinongy*). Not all introductions have been successful with crappie establishing only a moderate population and striped bass being of some controversy years after its introduction.

Northern pike have not been continuously stocked into Devils Lake since the present day fishery has become established. In a period from 1972 through 1980, pike were not stocked into Devils Lake yet sustained a relatively healthy fishery. Local references (11,12) and Game and Fish Department data (6) indicate that recreational fishing and northern pike reproduction was good during this period. This is during a period of time when lake elevations were increasing quite dramatically. It's interesting to note that during the period when Devils Lake elevations slightly decreased (in 1973) it was also during a time that pike reproduction was not found during sampling.

The present day walleye fishery was established beginning in 1970. At the time, northern pike were still the fish of choice for the recreational angler but walleye have since surpassed the pike as the angler's first choice. As with most other game fish species, the walleye population has fluctuated with water levels but is somewhat less dependent than is northern pike or yellow perch. The population is largely sustained through stocking activities of the North Dakota Game and Fish Department. Natural reproduction is limited even during high water years because of sparse substrate, e.g., clean rock/cobble, suitable for spawning. Salinities also affect survival of walleye but to a lesser extent than other species since natural reproduction is limited by other factors (5). Although water levels are not a factor for spawning and direct survival, they become a large factor for food production and the ultimate population structure.

During the same time frame as walleye, the yellow perch population became a popular winter fishery, thus bringing nation-wide notoriety to Devils Lake. This sport fishery actually began developing in 1969 when water elevations increased from 1412 feet msl to 1428 feet msl in 1983. A strong year class in 1982 was the primary reason for the rapid population expansion. The abundance of grass shrimp (*Gammarus lacustris*) in the lake was a large reason for the fast growth of yellow perch (13).

The fish assemblage of Devils Lake is unique to North Dakota since it is one of the few that exhibits a large proportion of the fish biomass being dedicated to desirable species, i.e., northern pike, walleye, yellow perch, white bass, and crappie. The major game species comprise over 99% of the fish biomass present, with white sucker and black bullhead comprising the remainder, i.e., <1%. White sucker have historically been present in Devils Lake (1,2,3,9) but the bullhead didn't appear in any records until 1969 (6). The source of bullheads may have been remnants of the experiments from the early 1900's but this is unlikely. It's also possible that the fish were introduced via "bait bucket" transfer. A primary rumor is the U.S. Fish and Wildlife Service (then the Bureau of Sport Fisheries and Wildlife) was responsible for stocking the fish into the lake. Under any scenario they have never presented a problem of over-population.

The fishery of Devils Lake is an important component of the local economy. Several creel surveys performed since 1988 show that the fishery of this large, natural lake directly contributes between $12 million and $27 million annually to the economy (14,15). The contribution is largely dependent on access to the fishery and the fishery itself. When fish populations are high (when water levels are adequate) fishing pressure and success is also high. When fish populations are consistently low (when water levels consistently recede), fishing pressure declines and participation follows suit.

The drought of the late 1980's and early 1990's was devastating to all fish populations of Devils Lake. Natural reproduction of most species was almost non-existent due to a combination of insufficient spawning habitat and increasing salinities. Although habitat conditions were harsh during this period the longer lived species, e.g., walleye and northern pike, were able to sustain populations because of their life span and some successful stocking activities. The white bass was actually able to expand its population and became a major component of the recreational fishery (16). A major concern during this time frame was relatively low winter dissolved oxygen levels, which became critically low during the latter stages of the drought (6). There was fear that the fishery would once again be lost because of major winter kill when lake elevations reached 1422 feet msl. This was speculative and not based on empirical data but on past observations that major winterkill conditions occurred between 1416 and 1422 msl (2, 3, 6).

Although stocking can and does occur frequently, the best fishery is established when fresher and higher water conditions are present. This is a result of better habitat, better food supply and more hospitable conditions. A number of changes has forced human intervention with varying results. The Creel Bay area has been lost for northern pike spawning. Changes have reduced the northern pike migration up Mauvais Coulee because of obstructions. Yet the dynamic nature of the fish has still allowed it to thrive when adequate climatic conditions are present. However, future changes and losses may be the final demise.

Salinities have also been a factor in the fishery of Devils Lake; although it's doubtful that they have been the direct cause of any catastrophic declines they certainly have an impact on fish reproduction. The major game species (yellow perch, walleye, and northern pike) tolerate salinities up to about 12,000 micromhos. Salinity tolerance is lower for reproduction than for adults. Reproduction of yellow perch, white bass, and crappie occur in those waters with conductivities less than 2,000 to 3,000 micromhos. On the upper end of the scale, fathead minnows and brook sticklebacks reproduce in salinities of about 6,000 and 11,000 micromhos/cm, respectively (17). This is not surprising since these two species are those that were found when game species were not present (2, 3, 7).

The fishery of Devils Lake has not been without controversy. The common thread of water levels has initiated the controversy revolving around the fishery even though it has never been the "driving force". During the drought of the early 1990's, the lake was perilously close to a massive winter kill. At that time water from the Missouri River via the Garrison Diversion was once again proposed to raise water levels and save the fishery. Alternatives such as partitioning the lake were also discussed. All options met with some opposition. It's recognized that a consistent supply of fresh water is a requisite for maintaining the fishery but it's not without some long term risks. Although salinities are not thought to have been a major factor in past fish kill situations, they could be so in the future. Import of Missouri River water would also be an introduction of salts since it is not distilled water. However, the runoff that has filled the lake in the past is also not distilled water. It's felt by some that salt is transported out of the basin during drought years via wind action and a cycle is maintained throughout the centuries. If the salt is not transported from Devils Lake it will eventually become as salty as the Great Salt Lake of Utah and not sustain fish life. An equally important issue is the import of species not currently in Devils Lake, e.g., common carp. The basis of the food web in Devils Lake is the grass shrimp. Carp would undoubtedly negatively impact that population as would species such as goldeye (*Hiodon alosoides*), which would have a direct impact on the existing fishery of Devils Lake.

Controversy has also come from high water years. In recent years, an outlet rather than an inlet has been seriously discussed. The introduction of striped bass, a non-native fish species, bacome a pivotal issue in possible transport of Devils Lake water to the Sheyenne River, which ultimately runs to Manitoba. Manitoba felt that introduction of striped bass would seriously harm their high valued fishery of Lake Winnipeg. Through minor research (18,19) and communications with Canada, this is no longer a major issue.

SUMMARY

Devils Lake has consistently shown a history of being a boom or bust fishery. The historic fishery was established largely by movement from other drainages and northern pike ultimately established a population. The current fishery is largely a result of human intervention through stocking activities with high water levels providing excellent conditions for sustaining fish populations. As water levels decline, fishing is extremely good for a period of time because of natural crowding. However, natural reproduction ultimately is inadequate to maintain fishable populations and stocking may be marginal for maintaining a stable fishery. History proves that consistent decline ultimately leads to the death of Devils Lake's fishery. Thus, a consistent water supply is required for maintenance of the sport fishery but the approach must be cautious. We will undoubtedly have another drought that will negatively affect the fishery. The options are somewhat limited, i.e., live with declining water levels or add an alternative source of water with unknown long term impacts. The benefits must be weighed against the costs before a final decision is made. Prior to that time the question of salt balance and transport needs to be answered. Without those answers we may be sentencing Devils Lake to a future death.

REFERENCES

1. Lord, H.W. 1884. Bull. U.S. Fish Comm. 4:351.
2. Woolman, A.J. 1896. Rept. U.S. Fish Comm. 1893:343-373.
3. Pope, T.E.B. 1909. Rept. Comm. Fish. 1907:3-23.
4. Upham, W. 1895. U. S. Geol. Surv. Mongraph XXV.
5. Hiltner, R. 1997. North Dakota Game and Fish Dept. Devils Lake, North Dakota.
6. North Dakota Game and Fish Department. 1995. Unpublished file notes. Bismarck, ND.
7. Young, R.T. 1924. Publ. N. Dak. Biol. Sta. 1924:1-116.
8. North Dakota Game and Fish Department. 1956. Bismarck, ND.
9. Van Whye, G. 1958. North Dakota Game and Fish Dept. Bismarck, ND.
10. Van Whye, G. 1959. North Dakota Game and Fish Dept. Bismarck, ND.
11. Burkett, B. 1997. North Dakota Game and Fish Dept. Devils Lake, ND.
12. Hildebrand, D. 1997. North Dakota Game and Fish Dept. Bismarck, ND.
13. Peterka, J.J. 1987. North Dakota Game and Fish Dept. Proj. F-2-R-34. Rept. No. A-1146.
14. Schwinden, C.J. and J.A. Leitch. 1984. Ag. Econ. Rept. No. 191. Dept. of Ag. Econ., North Dakota State University, Fargo, North Dakota.
15. Owen, J.B. and G.J. Power. 1989. North Dakota Game and Fish Dept. Proj. F-2-R-36, Job III-A, Rept. No. A-1178.
16. Brooks, L. and L. Schlueter. 1993. North Dakota Game and Fish Dept. Proj. F-2-R-39, Study III, Rept. No. 9.
17. Peterka, J.J. and J. Violett. 1988. Zool. Dept., North Dakota State University. Fargo, North Dakota.
18. Steinwand, T.R., L.R. Schlueter, and R. Hiltner. 1996. North Dakota Game and Fish Dept., Div. Rept. 23.
19. Hiltner, R. and T. Steinwand. 1996. North Dakota Game and Fish Dept., Div. Rept. 23a.

PHYTOPLANKTON DYNAMICS IN DEVILS LAKE UNDER VARYING HYDROLOGIC CONDITIONS

Harry V. Leland* and Wayne R. Berkas
U. S. Geological Survey, 3215 Marine Street, Boulder, CO 80303, and 821 East Interstate Ave., Bismarck, ND 58501

Annual variation in algal assemblages of hyposaline lakes in North America is poorly documented, as are the environmental factors contributing to changes in community structure. In the present study, annual and seasonal variation in algal biomass and structure of phytoplankton assemblages of the major sub-basins of Devils Lake (West, Sixmile, Creel, Main and East Bays) and East Devils Lake in North Dakota were examined in relation to ambient concentrations of major ions, trace elements and nutrients, and the standing crop of herbivores. The hydrologic budget of Devils Lake is tied closely to climate, and fluctuations in the balance between precipitation and evaporation result in major changes in lake level and major-ion concentrations. The early period of study (1988-1992) was one of decreasing lake levels; however, in subsequent years (1993-1994) historically large volumes of water flowed into the lake. Consistently high concentrations of reactive-P relative to inorganic-N indicate that Devils Lake and East Devils Lake are nitrogen limited; benthic fluxes are a dominant source of both constituents. The variation in SiO_2 concentration indicates a high rate of internal recycling related to phytoplankton production.

Samples taken to determine concentrations of chemical constituents in water and to quantify biomass and structure of algal assemblages were a composite of three grabs (Kemmerer) from equidistant depths of the photic zone (>1% of incident radiation). The constituents generally were uniformly distributed with depth due to wind-driven circulation, except when the lake was ice-covered. Community structure data for each season were summarized primarily by correspondence analysis (CA), an indirect-gradient ordination, and canonical correspondence analysis (CCA), a direct-gradient method (1).

Changes in lake level during the seven-year study were accompanied by relatively minor changes in algal biomass. In contrast, the annual variation in community structure of Devils Lake and East Devils Lake was large. Distributions of site scores on CCA axes 1 and 2 for winter (February) and spring (May) assemblages primarily expressed annual variation in species abundances; inter-site differences in assemblage structure were minor in comparison. Relations among measured environmental variables and algal abundances in summer (July-August) and autumn (October) expressed both annual and inter-site variation. Significant ($p<0.05$) variation of independent (variance inflation factor <10) environmental factors on the four CCA axes were as follows: nutrient concentrations (reactive-P, organic-N, SiO_2 and Ca) on CCA axis 1; temperature and total-P on axis 2; pH and Ca on axis 3; and inorganic-N and total-P on axis 4. Although a significant variable regulating algal community structure, dissolved solids concentration was not strongly correlated with any of the CCA axes. Thus major nutrient concentrations and water temperature accounted for more of the annual variation in phytoplankton structure than did salinity during the period of study.

The cyanophytes *Aphanothece* sp., *Chroococcus* sp., *Microcystis aeruginosa* and *Rhabdoderma sigmoidea* were the most abundant taxa in winter 1989 assemblages of Devils Lake and East Devils Lake. In contrast, the dominant taxa in Devils Lake in winter 1990 were the chlorophytes *Kirchneriella lunaris* and *Dunaliella* sp., the cryptophyte *Chroomonas* sp., and the diatom *Cyclotella meneghiniana*. *Aphanothece* sp. and *R. sigmoidea* were abundant again in winter 1990 in East Devils Lake, while *K. lunaris and C. meneghiniana* were co-dominants. The chlorophytes *Chlorocystis minor* and *K. lunaris* were dominant species in Devils Lake in February 1991 and 1992, whereas *Dunaliella* sp. was the most abundant species in East Devils Lake. *C. minor* was the most abundant algal species at all sites in February 1993 and 1994, but biomass of this species was less than that of the previous two years.

The cyanophytes *Aphanizomenon flos-aquae, M. aeruginosa, Aphanocapsa* sp. and *Pseudoanabaena mucicola* dominated the summer 1989 assemblages. *M. aeruginosa* and the diatom *Stephanodiscus* cf. *alpinus* were dominant taxa at all sites in the summer of 1990. *A. flos-aquae* also was a co-dominant in Devils Lake in summer 1990, whereas *Nodularia spumigena* was more abundant in East Devils Lake. *C. minor* and *M. aeruginosa* were abundant at all sites in the summer of 1991 and 1992. *Aphanocapsa* sp. was a co-dominant in summer 1991, whereas *A. flos-aquae* and *P. mucicola* were co-dominants in summer 1992. *A. flos-aquae* and *M. aeruginosa* dominated the summer 1993 assemblage, and *C. minor, M. aeruginosa and P. mucicola* dominated the summer 1994 assemblage.

Standing crops of secondary producers and planktonic consumers also varied substantially from year to year. Devils Lake supports a large standing crop of herbivorous zooplankton dominated by the copepods *Diacyclops thomasi* and *Leptodiaptomus sicilis;* the cladocerans *Ceriodaphnia quadrangula, Chydorus sphaericus, Daphnia pulex* and *Diaphanosoma birgei;* and the rotifers *Brachionus* spp., *Filinia longiseta* and *Keratella quadrata*.

1. ter Braak, C.J.F. (1986) Ecology 67:1167-1179.

HISTORICAL CLIMATE OF THE DEVILS LAKE REGION

Paul E. Todhunter*
Department of Geography, University of North Dakota, Grand Forks, ND 58202-9020

Introduction

Devils Lake, a permanent terminal lake which drains a 8,600 km^2 closed drainage basin (1), is a unique hydrologic system subject to rapid and significant lake-level fluctuations due to the dynamic nature of lake inflow, direct precipitation, and lake evaporation. Rapid and large lake-level fluctuations are a natural property of terminal lakes, particularly in the dry-subhumid environment experienced by the Devils Lake region (2). The objectives of this paper are to (1) review the historical climate of the Devils Lake region to establish a climate baseline, (2) document the nature of climate change and climate variability within the basin during the instrumented period, and (3) identify possible climate-related trends which may help explain the major lake-level changes that have taken place during the period of European settlement.

Methods

Because of the lack of high-quality long-term climate stations located within Devils Lake Basin, climate data for Langdon Experiment Station was used to document the historical climate of the basin. Langdon Experiment Station (48°45'N, 98°20'W, 492.3m) is located approximately 60 miles to the northeast of the City of Devils Lake and is a field research station maintained by the North Dakota Agricultural Extension Service. The station is part of the United States Historical Climatology Network (HCN), a collection of long-term monthly temperature and precipitation data for 1221 stations within the conterminous United States maintained for the purpose of analyzing long-term climate trends. All of the data are serially complete, and have been corrected for biases introduced by station moves, instrument changes, time-of-observation effects, and the artificial warming created by the urban heat island effect. The network is considered to be the best available dataset for the analysis of long-term climate trends (3). Although Langdon Experiment Station is not located within the basin proper, previous experience in quantifying the spatial correlation fields of mean annual temperature and annual precipitation support the assumption that the small distance separating the study site and the climate station (60 miles) has an insignificant effect upon the study results.

The climate variables examined include mean monthly air temperature, mean monthly maximum air temperature, mean monthly minimum air temperature, and monthly precipitation. Monthly totals were used to construct annual and seasonal values of these four variables to produce a broader array of climate variables. Annual totals are the mean (or total) of the 12 monthly values, while seasonal totals are averages (or totals) of the following months: winter (DJF), spring (MAM), summer (JJA), and fall (SON). Other variables were constructed from these primary data to provide a more complete picture of the study area historical climate. These included the 1) mean annual and mean seasonal daily temperature range, 2) the cold season (Oct-Mar) and warm season (Apr-Sep) precipitation totals, 3) the ratio of standardized winter to standardized summer precipitation (PRATIO3), and 4) the ratio of standardized cold season to standardized warm season precipitation (PRATIO6). These latter two variables identify any seasonal variation in the distribution of precipitation within a climatological year (4).

Annual precipitation data were also obtained for the Devils Lake KDLR climate station (48°07'N, 98°52'W, 446.2m) from the USGS Bismarck office (Greg Wiche, personal communication). A seasonal and annual historical time series of mean sunrise to sunset cloud amount was compiled for Bismarck WSFO (46°46'N, 100°45'W, 502.0m) to identify historical changes in cloudiness within the region. This information was obtained from the Historical Sunshine and Cloud Data in the United States data base (5). Although this data set contains the most complete and highest quality cloud amount time series available to the research community, a station move at Bismarck did occur in January 1940 when cloud amount observations were moved from the city center to the airport east of the city.

Different serially-complete period-of-records were available for the three sites (Langdon Experiment Station, Devils Lake KDLR, and Bismarck WSFO), the different climate variables (mean temperature, mean maximum temperature, mean minimum temperature, precipitation, mean cloud amount), and the various time steps (monthly, seasonal, annual). Consequently, the longest possible common serially-complete period-of-record was used to standardize the record length for all statistical analyses. This consisted of the period 1901-1994 (N=94) for all of the temperature and precipitation data, and the period 1907-1990 (N=84) for the cloud amount data.

Climatological analyses included constructing annual time series plots of all relevant variables, developing a 9-term binomial filtered time series of the variables to reduce the high frequency noise associated with interannual variability and to help identify lower frequency changes in the climate variables, and simple linear regression analyses of each climate variable against time to identify the presence and statistical significance of any historical trends in the data sets. Tests of significance are reported for all results, and should be viewed as the percent chance that the climate change obtained could arise due to purely random natural variations in a quasi-stationary climate which did not experience any long-term climate change.

Results

The plot of mean annual air temperature (TANN) from 1896-1994 at Langdon Experiment Station is shown in Figure 1.

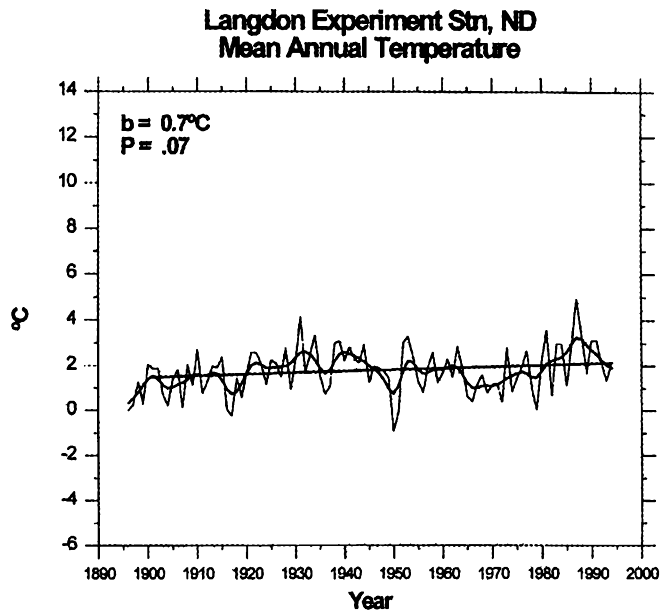


Figure 1: Mean annual air temperature (°C) at Langdon Experiment Station, ND, for the period 1896-1994, showing annual time series, 9-year filtered values, and trend line.

The time series exhibits a high degree of interannual variability, with warm years frequently followed by cool years, and vice versa. The filtered data indicate numerous warm and cold periods over the 99 years. A general warming trend occurred from 1896 through 1940, followed by a cooling trend from 1940 through 1965, followed by another warming trend from 1965 to the present. Results of the linear regression analysis for the period 1901-1994 are given in Table 1 and indicate a warming trend of 0.7°C per century. This trend has less than a 10% chance of being due to purely random variations in a stationary time series. The mean annual air temperature is actually the mean of the mean annual maximum (TMAX) and mean annual minimum (TMIN) air temperatures. Although both variables show a warming trend over the past century (Table 1), only the minimum (nighttime) trend is statistically significant. Because the minimum temperatures have warmed at a rate 6.3 times greater than the maximum (daytime) temperatures the mean annual daily temperature range (TRANN) has decreased at a rate of 1.1°C per century.

Table 1: Results of the trend analysis of annual climate variables against year for the period 1901-1994 at Langdon Experiment Station, ND. All trends are expressed as a rate per 100 years.

Variable	Trend	P-value of Trend
TANN	+0.7°C	.07
TMAX	+0.2°C	.64
TMIN	+1.3°C	<.01
TRANN	-1.1°C	<.01
PANN(L)	+19.6mm	.56
PANN(DL)	+46.8mm	.24
NANN	+20.9%	<.01
PRATIO3	-0.98	.02
PRATIO6	-0.56	.01

Annual precipitation data were examined for both the Langdon and Devils Lake stations. The annual precipitation time series for Devils Lake KDLR, shown in Figure 2, also indicates a high degree of interannual variability and the occurrence of several wet and dry spells throughout the record. There is no trend in the data from 1901 through 1970, after which a pronounced trend toward wetter conditions is evident. Although the station does show a trend toward greater precipitation, the rate of 46.8mm per century (Table 1) is not large enough to reject the null hypotheses of no change in the annual precipitation amount. Langdon Experiment Station exhibits an even smaller (and less significant) trend toward increased annual precipitation (Table 1).

Annual daytime cloud amounts (NANN) at Bismarck, WSFO (Table 1) reveal a very significant trend toward increased daytime cloud amounts for the period 1907-1990. Assuming that nighttime cloud amount totals follow the same pattern, these results are physically consistent with the trends noted in TMAX, TMIN, TRANN and PANN. Clouds, in general, increase nighttime temperatures, enhance precipitation, and suppress increases in daytime temperature.

Aggregating climate data to an annual time scale can obscure the seasonal structure of climate change which may be considerable, and which can offer important physical insights to the nature of climate change (6). Consequently, all of the data were examined on a seasonal basis as well. The results of these trend analyses are summarized in Table 2.

Table 2: Results of regression analysis of seasonal climate variables against year for the period 1901-1994 at Langdon Experiment Station, ND. All trends are expressed as a rate per 100 years.

Variable	Trend	P-value of Trend	Variable	Trend	P-value of Trend
Winter			Spring		
TWIN	+0.8°C	.45	TSPR	+1.0°C	.16
TXWIN	+0.8°C	.43	TXSPR	-0.4°C	.66
TNWIN	+2.5°C	.02	TNSPR	+1.4°C	.03
TRWIN	-1.6°C	<.01	TRSPR	-1.8°C	<.01
NWIN	+21.7%	<.01	NSPR	+23.8%	<.01
PWIN	-21.2mm	.01	PSPR	+7.3mm	.64
Summer			Fall		
TSUM	+1.4°C	<.01	TFAL	-0.4°C	.45
TXSUM	+1.3°C	.05	TXFAL	-1.0°C	.12
TNSUM	+0.5°C	.17	TNFAL	+0.7°C	.19
TRSUM	+0.7°C	.17	TRFAL	-1.7°C	<.01
NSUM	+17.3%	<.01	NFAL	+20.6%	<.01
PSUM	+48.4mm	.05	PFAL	-14.6mm	.38

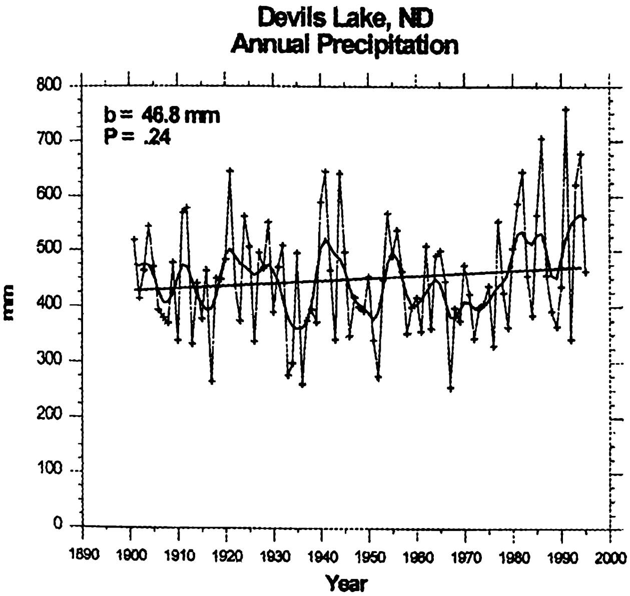


Figure 2: Annual precipitation (mm) at Devils Lake KDLR, ND, for the period 1901-1995, showing annual time series, 9-year filtered values, and trend line.

Mean winter air temperature (TWIN) has warmed during the historical record though not at a statistically significant level. Mean minimum winter temperature (TNWIN) has warmed at a rate 3.0 times greater than the mean maximum winter temperature (TXWIN), resulting in a significant decrease in the mean winter daily temperature range (TRWIN). Similar trends are present in the spring temperature data, with the exception that mean maximum spring temperature has actually decreased, although the trend is not significant. Summer air temperature trends depart considerably from these patterns. The magnitude of the mean summer temperature (TSUM) warming trend is larger (and more statistically significant) than for any other climate period. Furthermore, the mean maximum summer temperature (TXSUM) has warmed at a greater rate than the warming trend for the mean minimum summer temperature (TNSUM). Mean maximum summer (daytime) air temperature has increased at a rate of 1.3°C per century, a value 2.3 times larger than that observed for the mean minimum summer air temperature. As a result, the mean summer daily temperature range has actually increased over the historical period. The mean fall air temperature (TFAL) has decreased over the study period, as has the mean maximum fall temperature (TXFAL). The mean minimum fall temperature (TNFAL) has warmed, though not at a significant rate. Mean daytime cloud amount shows a significant trend toward increased cloudiness for all seasons.

Although the annual precipitation time series at Langdon Experiment Station did not indicate a statistically significant trend toward increased precipitation, winter and summer seasonal precipitation totals indicate significant trends toward decreased and increased totals, respectively. Spring and fall trends indicate no significant change over time. When the effects of these opposite trends are quantified by the standardized ratios of winter to summer precipitation (PRATIO3) and cold season to warm season precipitation (PRATIO6) a pronounced trend toward an increased concentration of annual precipitation during the summer/ warm season becomes evident (Table 1).

Discussion

Mean annual air temperature within the Devils Lake region has increased at a rate comparable to the magnitude of the global mean temperature increase of 0.6°C observed over the past century (7). Karl et al. (8) report increases in mean annual temperature on the order of 1-2°C over the period 1900-1994 for the nine climate divisions in the state, while Todhunter (2) found a 1.3°C warming for the central region of the state for the period 1895-1990. Results of individual station analyses over the period 1948-1988 also support a strong general warming trend in the region (6, 9). The warming trend in Devils Lake region is similar in nature to warming patterns previously reported at the global (7), national (6) and individual station (9) scales. Most of the historical warming has been as a result of an increase in the mean minimum (nighttime) temperatures. The seasonal distribution of the warming has been concentrated during winter, with spring and fall temperature trends actually indicating a decrease in the mean maximum (daytime) temperatures. Only summer shows a significant increasing trend in the mean maximum temperature. This indicates that most of the warming in Devils Lake region has been largely benign from an ecological/hydroclimatological standpoint. Similar findings have been observed at Jamestown State Hospital (9).

The annual precipitation time series for the Langdon and Devils Lake stations suggest a change toward wetter conditions, although both trends could be due to random variations. More significant is the observation that the seasonal distribution of precipitation has changed, with a smaller contribution from winter and a larger proportion from summer precipitation. Decreased winter precipitation (PWIN) suggests a decreased winter basin snowpack. Karl et al. (8) found a 5-10% decrease in climate division annual precipitation over a comparable time period. The station data examined by Lettenmaier et al. (6) over a more recent time period revealed no clear and coherent general pattern for the northern Plains. The increase in summer maximum temperature, daytime cloud amount, and precipitation suggests an increase in summer convective activity and enhanced precipitation intensity. This observation has been demonstrated by Karl et al. (10) who found a significant increase in the proportion of total precipitation contributed by extreme one-day events for the conterminous United States, particularly in summer, along with a decrease in the proportion of total precipitation contributed by light-moderate one-day events.

The trend toward increased daytime cloud amount for all seasons is consistent with global cloud amount trends reported by Karl et al. (7), as well as local precipitation trends at Langdon and Devils Lake. Furthermore, they are physically consistent with the general increase in mean minimum temperature and mean daily temperature range reported at the global, regional and local scales (6, 7, 9). The common explanation for these findings is the global and regional increase in tropospheric sulfate aerosols due to sulfur emissions and biomass burning (7).

The water balance implications of these temperature, precipitation and cloud amount trends for Devils Lake are not certain, and we can only offer hypotheses for further research. We do know, in general, that interannual variations in lake-level are more sensitive to precipitation changes than to evaporation changes (11), that interannual variations in lake-level at Devils Lake are most sensitive to lake area (1), and that lake evaporation variations are more sensitive to cloud amount variations (through its control on solar irradiance) than to changes in the air temperature regime (12).

Most global climate models project a significant increase in evaporative demand under a doubled CO_2 atmospheric concentration, and an earlier spring thaw. Although there is some evidence to support an earlier spring thaw in the northern Plains (6), the seasonal mean maximum temperature and mean cloud amount trends observed in the Devils Lake region are not entirely supportive of an enhanced evaporative demand. Most of the observed warming has been benign with respect to evaporation and transpiration, occurring at night or in the winter when evapotranspiration is negligible. Spring and fall mean maximum temperatures have actually fallen during the historical period. Only the summer mean maximum temperature shows an increase consistent with increased lake and basin evapotranspiration. Furthermore, the significant increase in daytime cloud amount totals almost certainly would result in decreased solar irradiance and reduced evapotranspiration. In addition, the direct effect of increased atmospheric CO_2 could be expected to have an anti-transpirant effect upon basin transpiration. When examined as a whole the climate record is more supportive of a decrease in lake evaporation and basin evapotranspiration over time than the traditional assumption of increased evaporative demand. This hypothesis is supported by the work of Peterson et al. (13) who report a decrease in warm season mean daily pan evaporation in the United States over the past 45 years.

Direct precipitation onto the lake surface is the most important water input to Devils Lake (1). The climate record suggests a possible trend toward increased precipitation although this cannot be stated with certainty due to the small magnitude of the increase and the limited number of stations examined within the region. The seasonal distribution of precipitation has, however, been changing, with a greater proportion coming during the warm season.

Surface water inflow also serves as a major input to Devils Lake. Previous work has demonstrated an increase in the mean monthly streamflow for September-December for the Upper Mississippi River Valley region (12), as well as an increase in mean annual, winter and spring streamflow for individual stations within the northern Plains over the period 1948-1988 (6). As the regional antecedent moisture content increases, the potholes and lakes which feed into Devils Lake may be losing their capacity to buffer the lake from basin-wide precipitation, leading to an increase in surface-water inflow to Devils Lake.

Lake-level fluctuations respond to the balance between the primary lake inputs (direct precipitation and surface inflow) and lake outputs (evaporation). Normally, lake levels in Devils Lake exhibit a strong seasonal pattern with a spring/summer maximum and a fall minimum (1). One hypothesis is that some combination of increased cloud amount, decreased lake evaporation, decreased basin evapotranspiration, increased surface-water inflow, and increased summer precipitation from intense storms may be producing a long-term decrease in the summer lake-level drawdown. This would progressively lead to a long-term increase in basin moisture storage during the fall which, in turn, would contribute toward a long-term general lake-level rise. Lettenmaier et al. (6) caution, however, that possible water management effects may explain or contribute to the streamflow increases which they observed.

Devils Lake is a unique hydrologic system in which the lake-level fluctuates in response to a spatially and temporally dynamic set of water balance parameters. This review of the historical climate, along with observations on the regional hydroclimatology made by other researchers, indicates that a complex set of natural (and possibly human) factors are interacting to produce the dramatic lake-level rise observed at Devils Lake since 1940.

References

1. Wiche, G.J. and Pusc, S.W. (1994) Hydrology of Devils Lake Area, North Dakota, ND State Water Commission, Water Resources Investigation 22, 24 pp.
2. Todhunter, P.E. (1995) Great Plains Res 5, 137-162.
3. Easterling, D.R., Karl, T.R., Mason, E.H., Hughes, P.Y., and Bowman, D.P. (1996) United States Historical Climatology Network (U.S. HCN) Monthly Temperature and Precipitation Data. ORNL/CDIAC-87, NDP-019/R3. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, TN. 280 pp.
4. Hanson, K., Maul, G.A. and Karl, T.R. (1989) Geophys Res Lett 16, 49-52.
5. Steurer, P.M. and Karl, T.R. (1991) Historical Sunshine and Cloud Data in the United States. ORNL/CDIAC-43, NDP-021/R1. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, TN. 154 pp.
6. Lettenmaier, D.P., Wood, E.F. and Wallis, J.R. (1994) J Climate 7, 586-607.
7. Karl, T.R., Jones, P.D., Knight, R.W., Kukla, G., Plummer, N., Razuvayev, V., Gallo, K.P., Lindseay, J., Charlson, R.J. and Peterson, T.C. (1993) Bull Amer Meteorol Soc 74, 1007-1023.
8. Karl, T.R., Knight, R.W., Easterling, D.R., and Quayle, R.G. (1996) Bull Amer Meteorol Soc 77, 279-292.
9. Todhunter, P.E. (1993) Proc ND Acad Sci 47, 5.
10. Karl, T.R., Knight, R.W. and Plummer, N. (1995) Nature 377, 217-220.
11. Mann, M.E., Lall, U. and Saltzman, B. (1995) Geophys Res Lett 22, 937-940.
12. Lins, H.F. and Michaels, P.J. (1994) Eos 75, 281, 284-285.
13. Peterson, T.C., Golubev, V.S. and Groisman, P. Ya. (1995) Nature 377, 687-688.

A HISTORY OF LAKE-LEVEL FLUCTUATIONS FOR DEVILS LAKE, NORTH DAKOTA, SINCE THE EARLY 1800'S

Gregg J. Wiche*, U.S. Geological Survey, Water Resources Division, 821 East Interstate Avenue, Bismarck, ND 58501
R.M. Lent, U.S. Geological Survey, Water Resources Division, 28 Lord Road, Suite 280, Marlborough, MA 01752
W.F. Rannie, Department of Geography, University of Winnipeg, Winnipeg, Manitoba, R3B 2E9, Canada
Aldo V. Vecchia, U.S. Geological Survey, Water Resources Division, 821 East Interstate Avenue, Bismarck, ND 58501

INTRODUCTION

The Devils Lake Basin is a 3,810-square-mile (mi²) closed basin (fig. 1) in the Red River of the North Basin. About 3,320 mi² of the total 3,810 mi² is tributary to Devils Lake; the remainder is tributary to Stump Lake. The level of Devils Lake (fig. 2) has risen rapidly in response to above-normal precipitation from the summer of 1993 to the present (1997), and 30,000 acres of land around the lake have been flooded. The above-normal precipitation also has caused flooding elsewhere in the Devils Lake Basin. State highways near Devils Lake are being raised, and some local roads have been closed because of flooding.

In response to the flooding, various planning studies are being conducted by Federal agencies and the North Dakota State Water Commission. Most of the studies include options to store water in the Devils Lake Basin and to provide an outlet to the Sheyenne River via Devils Lake or East and West Stump Lakes. All of the options being considered will be based on past lake-level fluctuations. The purpose of this paper is to briefly describe the hydrology of the Devils Lake area in relation to lake-level fluctuations and to describe recorded and inferred lake-level fluctuations since the early 1800's.

DISCUSSION

Before 1979, streamflow from the principal streams (fig. 1) draining the Devils Lake Basin flowed into the interconnected chain of lakes (Sweetwater Lake, Morrison Lake, Dry Lake, Mikes Lake, Chain Lake, Lake Alice, and Lake Irvine), and all streamflow from the chain of lakes flowed downstream through Big Coulee into Devils Lake (fig. 1). In 1979, the drainage pattern in the basin was modified by the construction of Channel A, which connects Dry Lake to Sixmile Bay on Devils Lake. The upstream chain of lakes, in addition to wetlands in the Devils Lake Basin, provide significant water storage in many years and decrease the runoff that otherwise reaches Devils Lake. For example, during 1965-67, the upstream chain of lakes stored at least 112,000 acre-feet (acre-ft) of water. However, since 1993, streamflow into the chain of lakes and precipitation falling on the lakes has exceeded lake evaporation, and little storage has been available in late fall at the time of freezeup during 1993-96. Thus, the relation between climate variability and lake-level fluctuations of Devils Lake is complicated by the chain of lakes.

The long-term water budget of Devils Lake can be simplified into three components; precipitation falling on the lake, inflow to the lake, and evaporation from the lake surface. Ground water is only a small percentage of the inflow. Based on about 130 years of lake-level record, 100 years of climate record, and 50 years of hydrologic record, the long-term inputs from precipitation and inflow are about equal. However, during periods of relatively low effective-moisture (precipitation minus evaporation) conditions, such as during the drought of the late 1980's, tributary inflow was minimal and less than precipitation falling on the lake. During periods of relatively high effective-moisture conditions, such as during the mid-1990's, inflow is substantially greater than precipitation falling on the lake.

Most of the inflow to Devils Lake during any year is strongly dependent on the antecedent soil-moisture conditions in the basin and the amount of water stored in the lakes and wetlands in the basin. Therefore, a large part of the total inflow to Devils Lake can be attributed to a few years of exceptionally large runoff. For example, total inflow to Devils Lake for 1993-96 accounts for 31 percent of all inflow to Devils Lake for 1950-96.

Annual evaporation from Devils Lake has less variability than inflow, and annual lake-level declines from evaporation are small in comparison to the rises caused by large runoffs. Therefore, the lake level at any time reflects climatic fluctuations on a decadal scale and is dominated by rapid rises during relatively uncommon wet periods and by long-term, relatively slow declines during more common years of little runoff. Thus, the 5.0-foot (ft) lake-level rises that occurred in 1993 and in 1995 cannot be eliminated by 1 year of evaporation.

Since glaciation, the level of Devils Lake has fluctuated from about 1,457 ft above sea level, the natural spill elevation of the lake to the Sheyenne River, to 1,400 ft above sea level (1). Lake-level fluctuations for the lake during the last 4,000 years are shown in a generalized graph by Bluemle (2). According to Bluemle (2), the lake has gone dry about six times during the last 4,000 years and has spilled to the

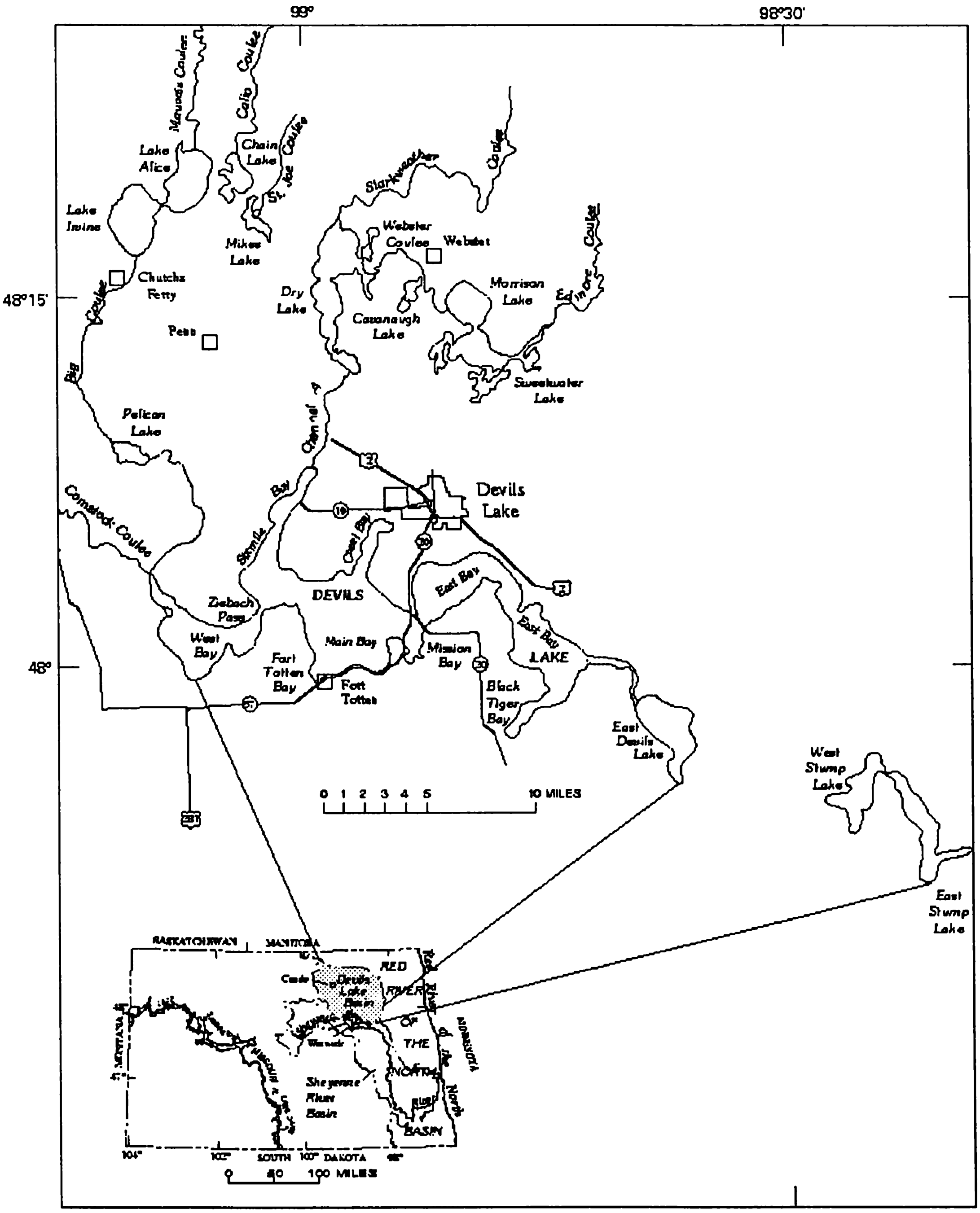


Figure 1. Location of the Devils Lake Basin.

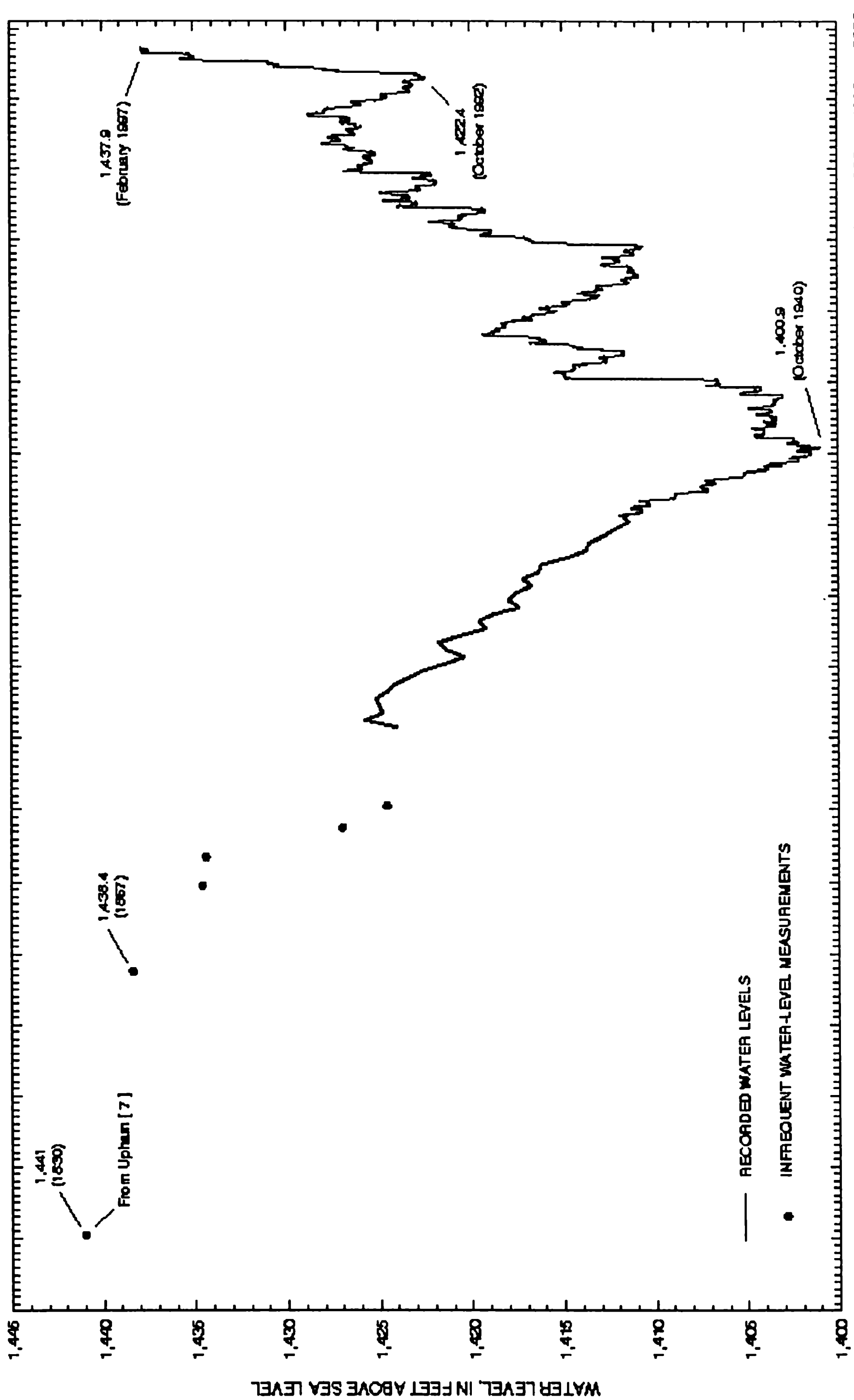


Figure 2. Historic water level for Devils Lake, 1820-1997.

Sheyenne River at least twice. Bluemle (2) also stated that the lake has repeatedly overflowed to East and West Stump Lakes.

Lake levels were recorded sporadically from 1867 to 1901 when the U.S. Geological Survey established a gaging station on Devils Lake. From 1867 to the present (1997), the lake level has fluctuated between a maximum of 1,438.4 ft above sea level in 1867 and a minimum of 1,400.9 ft above sea level in 1940 (fig. 2). On February 1, 1997, the lake level was 1,437.9 ft above sea level, about 15.3 ft higher than the level recorded in February 1993 and the highest level in about 130 years. The 130-year lake-level record is very short compared to the much longer geologic record; however, large lake-level fluctuations have occurred during those 130 years. Studies of lake-level fluctuations of Devils Lake (1, 2, 3, 4, 5) indicate that large, frequent fluctuations of 20 to 40 ft occur every few hundred years. A rising or declining lake level is a more normal condition for Devils Lake than a stable lake level (6).

Hydrologic data for Devils Lake and climatic inference from archival records for the Red River of the North Basin indicate that lake levels from 1800 to 1870 were, in fact, higher than lake levels since 1870. Higher lake levels imply that runoff probably was greater, and, thus, effective moisture also probably was greater. On the basis of tree-ring chronology, Upham (7) inferred that the level of Devils Lake was 1,441 ft above sea level in 1830. High lake levels during the 19th century are supported by climatic inference from documents of fur traders, explorers, missionaries, and settlers. The documents have been used to compile a 200-year flood history for the Red River of the North Basin (8, 9, 10). Based on historical documents, the largest 19th-century floods (1826, 1852, and 1861) were significantly larger than the 20th-century floods, and several 19th-century floods were about the same magnitude as the largest 20th-century floods (1950 and 1979). The entire flood record of the 19th century indicates flooding in the Red River of the North Basin, which includes the Devils Lake Basin, occurred more frequently from 1800 to 1870 than since 1870. As in the 20th century, 19th-century floods generally were spring snowmelt floods. Summer precipitation is difficult to quantify from historic records, but a striking feature of the 19th-century record is the number of summer floods and high-water events that occurred from 1800 to 1870. Summer flooding, which has been unusual in the 20th century, was much more frequent from 1800 to 1870 when events similar in magnitude to events of the extremely wet summer of 1993 occurred on numerous occasions, most notably in 1806 and 1849-52 (11).

The only known published dendroclimatologic study for the Devils Lake area was conducted by Will (12). Dendrochronologic data were collected from bur oak trees near Bismarck and used to characterize the annual precipitation from 1406 through 1940 as wet, dry, or average. For the entire period of record, the number of years characterized as wet and dry were almost identical (12). Will (12) identified 48 wet years and 22 dry years between 1776 and 1870, which is about the same period as that of archival records referred to in this study. The remaining years were identified as average. Thus, the ratio of wet to dry years was about 2 to 1. However, from 1876 to 1940, a time when the level of Devils Lake generally declined, the ratio of wet to dry years was about 1 to 2. Thus, Will's results (12) indicate that summers had greater effective moisture in the 19th century than in the 20th century. Dendrochronology has advanced greatly since the time of Will's work. For example, Stockton and Meko (13) used tree rings to construct a nearly 300-year drought history of several regions in the northern and central Great Plains. Except from 1820 to 1824, droughts were relatively infrequent from 1800 to about 1860, and the 31 years from 1824 to 1855 were almost drought-free.

Laird et al. (14) used fossil diatom assemblages to compile a 2,300-year proxy record of salinity fluctuations of Moon Lake [about 84 miles (mi) south-southeast of Devils Lake]. Laird et al. (14) concluded that whereas before about A.D. 1200, drought intensity and frequency were greater than during the 1930's, the past c. 750 years (coinciding approximately with the "Little Ice Age") have been marked by generally lower salinity, implying wetter and cooler conditions. The lowest inferred salinity in the entire record occurred during the 19th century. In support of this conclusion, Laird et al. (14) cited data presented by Clark (15) that indicate forest fire frequency, inferred from the charcoal content in varved lake sediments in a region of northwestern Minnesota, was relatively low during most of the 19th century.

Other evidence indicates that summers were, on average, somewhat cooler during the 19th century than during the 20th century. Maps compiled by Wahl and Lawson (16) from instrument records for 1850-70 indicate mean July-August temperatures in the Devils Lake area were about 1°C cooler than mean July-August temperatures for 1931-60. Breakup and freezeup dates for the Red River of the North at Winnipeg indicate that the mean ice-free season in the 19th century was nearly 3 weeks shorter than in the 20th century and the mean spring and fall temperatures were about 2.5°C cooler (17). Robertson et al. (18) indicated a similar pattern of temporal changes in ice cover for Lake Mendota, Wis., from 1855 to 1991. The mean frost-free season at Winnipeg was about 2 weeks shorter in the 19th century than in the 20th century, mainly because of earlier fall frosts (19, 20). Findings on the ice-free season and on seasonal temperatures are in agreement with findings of Wahl and Lawson (16), who indicated that mean temperatures in all seasons were cooler for 1850-70 than for 1931-60.

Published biologic data further support the hypothesis that the level of Devils Lake during the first half of the 19th century was higher than at present (1997), and, thus, effective moisture also was higher. Devils Lake supported an extensive natural fishery throughout most of the 1820's and 1830's. During the snowy winter of 1825-26, settlers, trappers, and traders who had run out of food supplies left Pembina for Devils Lake to fish for pike (21). In 1839, the Fremont and Nicollet Expedition found an abundance of fish in Devils Lake. Fremont said, "It is a beautiful sheet of water, the shores being broken in pleasing irregularity by promontories and islands." During 1884-87, commercial fishing reached its peak and 500 to 1,000 pounds of fish per day were leaving Devils Lake (22). Fisheries such as those that existed throughout the 1820's and 1830's and in the 1880's would take years to develop and probably would occur only at lake levels greater than 1,420 ft above sea level (Terry Steinwand, North Dakota Game and Fish Department, oral commun., 1995). Therefore, a logical assumption is that Devils Lake was relatively fresh and lake levels were higher than 1,425 ft above sea level for several years before 1825-26 and several years before the 1880's (Randy Hiltner, North Dakota Game and Fish Department, oral commun., 1996).

Sporadic lake-level measurements were made on East and West Stump Lakes from 1949 through 1979 and from 1993 through 1995. Between 1949 and 1995, the level of West Stump Lake ranged from about 1,394 ft above sea level in the dry years to about 1,400 ft above sea level in the wet years, and the level of East Stump Lake ranged from about 1,382 ft above sea level in the dry years to about 1,385 ft above sea level in the wet years. Based on lake-level measurements through 1995, no sustained, major lake-level changes occurred on East and West Stump Lakes from 1949 through 1992.

Although no streamflow gages exist in the Stump Lake drainage basin, quarterly lake-level measurements since 1993 and observations of local landowners and North Dakota State Water Commission and U.S. Fish and Wildlife Service personnel indicate that a relatively large amount of tributary runoff into West Stump Lake occurred late in the summer of 1993, and, by February 1994, the level of West Stump Lake was 1,395.8 ft above sea level. By January 1995, East and West Stump Lakes were joined, and the lake level was 1,398 ft above sea level. On July 22, 1996, the level of Stump Lake was 1,403.8 ft above sea level, the highest level in about 75 years. However, the level of Stump Lake was 1,423 ft above sea level in 1881 (1), indicating either Devils Lake spilled to Stump Lake sometime before 1867 (possibly in the spring of 1826) or a very rare runoff or series of runoffs (much greater than the runoff from 1993 through 1996) occurred in the Stump Lake Basin before 1881. Runoff from 1993 through 1996 increased the volume of water stored in Stump Lake by 77,000 acre-ft, but another 156,000 acre-ft of water would be needed to increase the level of Stump Lake to 1,423 ft above sea level.

A statistical water mass-balance model developed for Devils Lake was used to determine ranges for feasible lake levels that could have occurred from 1825 to 1890. Model results indicate only about a 5-percent chance that a lake level of 1,425 ft above sea level or less occurred from 1825 to 1890.

SUMMARY

The principal streams draining the Devils Lake Basin flow into the interconnected chain of lakes, and Big Coulee and Channel A connect the chain of lakes to Devils Lake. The relation between climate variability and lake-level fluctuations of Devils Lake is complicated by the chain of lakes. The lake level at any time reflects past climatic fluctuations on a decadal scale and is dominated by rapid rises during relatively uncommon wet periods and by long-tern, relatively slow declines during more common years of little runoff.

Devils Lake has gone dry several times during the last 4,000 years and has spilled to the Sheyenne River at least twice. Lake levels have been recorded at various intervals since 1867, and, although the 130-year period of record is relatively short compared to the geologic record, large fluctuations have occurred during those 130 years. Climatic inference from archival records for the Red River of the North Basin indicate that lake levels from 1800 to 1870 were higher than lake levels since 1870. In 1830, the level of Devils Lake was 1,441 feet (ft) above sea level, and, based on evidence from the fishery at Devils Lake and an understanding of the water balance of the lake, lake levels probably were higher than 1,425 ft above sea level for several years before and after 1830. Research related to floods on the Red River between 1825 and 1870 and climatic research for that period indicates that lake levels remained high (greater than 1,425 ft above sea level) between 1825 and 1870.

REFERENCES

1. Aronow, S. (1957) On the postglacial history of the Devils Lake region, North Dakota. Jour Geology 65, 410-427.
2. Bluemle, J. (1996) From the state geologist. North Dakota Geol Soc Newsletter 23(1), 1-2.
3. Brooks, C.E.P. (1951) Geological and historical aspects of climatic change, in Compendium of Meteorology (Malone, T.F., ed). Boston, American Meteorological Society, 1004-1018.
4. Aronow, S. (1955) Problems in late Pleistocene and Recent history of the Devils Lake region, North Dakota. Madison, University of Wisconsin, unpublished Ph D dissertation, 125.
5. Callender, E. (1968) The postglacial sedimentology of Devils Lake, North Dakota. Grand Forks, University of North Dakota, unpublished Ph D Dissertation 312.
6. Wiche, G.J. and Vecchia, A.V. (1996) Lake-level frequency analysis for Devils Lake, North Dakota. U.S. Geological Survey Water-Supply Paper 2469, 57.
7. Upham, W. (1895) The glacial Lake Agassiz. U.S.

Geological Survey Monograph No. 25, 658.

8. Miller, J.E. and Frink, D.L. (1984) Changes in flood response of the Red River of the North Basin, North Dakota, 1952-60. U.S. Geological Survey Water-Supply Paper 2243, 103.

9. Booy, C. and Morgan, D.R. (1985) The effect of clustering of flood peaks on a flood risk analysis for the Red River. Canadian Jour Civil Eng 12, 150-165.

10. Rannie, W.F. (1990a) Overview of geology and recent climate of the Red River Basin, in Water Quantity—TooMuch—Too Little. Proceedings, 7th Annual Red River Basin Land and Water International Summit Conference, November 16-17, 1989, 4-16.

11. Blair, D. and Rannie, W.F. (1994) "Wading to Pembina"—1849 spring and summer weather in the valley of the Red River of the North and some climatic implications. Great Plains Research 3, 3-26.

12. Will, G.F. (1946) Tree ring studies in North Dakota. North Dakota Agricultural College, Agricultural Experiment Station Bulletin 328, 24.

13. Stockton, C.W. and Meko, D.M. (1983) Drought recurrence in the Great Plains as reconstructed from long-term tree-ring records. Jour Climate and Appl Meteorology 22, 17-29.

14. Laird, K.R., Fritz, S.C., Maasch, K.R. and Cumming, B.F. (1996) Greater drought frequency before AD 1200 in the Northern Great Plains. Nature 384, 552-554.

15. Clark, J.S. (1988) Effect of climate change on fire regimes in northwestern Minnesota. Nature 334, 233-235.

16. Wahl, E.W. and Lawson, T.L. (1970) The climate of the midnineteenth century United States compared to the current normals. Monthly Weather Review 98, 259-265.

17. Rannie, W.F. (1983) Breakup and freezeup of the Red River at Winnipeg, Manitoba, Canada, in the 19th century and some climate implications. Climatic Change 5, 283-296.

18. Robertson, D.M., Ragotzkie, R.A. and Magnuson, J.J. (1992) Lake ice records used to detect historical and future climatic changes. Climatic Change 21, 407-427.

19. Rannie, W.F. (1990b) Change in frost season characteristics in Winnipeg, 1872-1988. Climatological Bulletin 24, 168-177.

20. Rannie, W.F. (1992) The role of frost as a limiting factor to wheat production in the Red River settlement. Prairie Forum 17, 1-12.

21. Gunn, D. (1880) History of Manitoba. MacLean, Roger and Company, Ottawa.

22. Babcock, H.E. (1952) The historical geography of Devils Lake. M Sc Thesis, University of Washington, 199.

USING CONDITIONAL SIMULATIONS OF THE LEVEL OF DEVILS LAKE, NORTH DAKOTA, TO RECONSTRUCT HISTORICAL HYDROLOGIC CONDITIONS

Aldo A. Vecchia*, U.S. Geological Survey, Water Resources Division, 821 East Interstate Avenue, Bismarck, ND 58501
Gregg J. Wiche, U.S. Geological Survey, Water Resources Division, 821 East Interstate Avenue, Bismarck, ND 58501

SUMMARY

A statistical water mass-balance (WMB) model developed for Devils Lake can be used to simulate possible future lake levels or possible historical lake levels and hydrologic inputs. The future lake levels are simulated from current and past hydrologic inputs, and the historical lake levels and hydrologic inputs are simulated from limited historical lake levels. The simulations are conditioned on known lake levels or hydrologic inputs and are, therefore, called conditional simulations. For this paper, the WMB model was used to generate conditional simulations of historical lake levels and precipitation, evaporation, and inflow values for Devils Lake for 1826-90. Output from the model was used to determine ranges for feasible lake levels and precipitation and inflow values for 1826-90. Data indicate that the more recent dry and wet periods are extreme when compared to the 1830's through the 1890's.

INTRODUCTION

The Devils Lake Basin is a 3,810-square-mile (mi^2) closed basin in northeastern North Dakota (fig. 1). Wiche (1) described the basin and discussed historical lake levels and recent flooding problems in Devils Lake, which is located in the basin, and Wiche and Vecchia (2) developed a statistical water mass-balance (WMB) model for the lake. The study for which the WMB model was developed was conducted in cooperation with the North Dakota State Water Commission to assist the U.S. Army Corps of Engineers and water-resource managers in decisions regarding proposed flood-control or lake-stabilization projects. The WMB model is used to compute the total volume (mass) of water stored in Devils Lake, given precipitation on the lake surface, evaporation from the lake surface, and inflow to the lake. The model also includes a time-series model to generate future sequences of precipitation, evaporation, and inflow from which the probability of future lake-level rises or declines can be determined.

The primary use for the WMB model to date has been to determine the probabilities of future lake levels, given the current lake level and antecedent values of hydrologic inputs to the model. The generated sequences of possible future lake levels are called conditional simulations because the sequences are conditioned on antecedent values of hydrologic inputs. For example, the most recent runs from the WMB model, beginning January 1, 1997, when the lake level was 1,437.8 feet (ft) above sea level, indicate that the lake has a 10-percent (1 in 10) chance of reaching 1,442.5 ft above sea level sometime in 1997 and a 10-percent chance of reaching 1,444 ft above sea level by the year 2000.

When using the WMB model to determine the probability of future lake levels, antecedent values of precipitation, evaporation, and inflow are known, and future lake levels are unknown. For this paper, the model was used in a different context—historical lake levels were known, but precipitation, evaporation, and inflow values were unknown. Historical lake levels were assumed to be within intervals that also included the known lake level for given years. Conditional simulations from the WMB model were used to reconstruct a sequence of feasible precipitation, evaporation, and inflow values that could produce the historical lake levels and to reconstruct the range of feasible lake levels that could occur between the known lake levels. In the conditional simulations, historical sequences of precipitation, evaporation, and inflow values were generated from a time-series model that was fitted using known inputs and lake levels from 1950 through 1993. However, for each sequence, the parameters of the time-series model were selected randomly from a parameter-uncertainty distribution that simulates the effects of changing hydrologic conditions. The conditional simulations were used with limited historical lake levels to reconstruct historical lake levels and precipitation and inflow values for Devils Lake for 1826-90.

CONDITIONAL SIMULATIONS FOR 1826-90

Based on tree-ring chronology, Upham (3) concluded that Devils Lake spilled to Stump Lake (spill elevation 1,445 ft above sea level) sometime before 1830 and was below about 1,441 ft above sea level from 1830 to 1890. Devils Lake probably spilled to Stump Lake in 1826 when severe flooding occurred in the Red River of the North Basin. In 1867, the lake level was 1,438.4 ft above sea level, and, in 1890, the level was 1,424.6 ft above sea level (1). Constraints for the conditional simulations were: the starting lake level in 1826 was exactly 1,445 ft above sea level; the level between 1830 and 1890 was no higher than 1,443 ft above sea level; the level in 1867 was 1,438.4 ft above sea level (plus or minus 1 ft); and the level in 1890 was 1,424.6 ft above sea level (plus or minus 1 ft). The WMB model was used to generate sequences of simulated lake levels. Each sequence started in

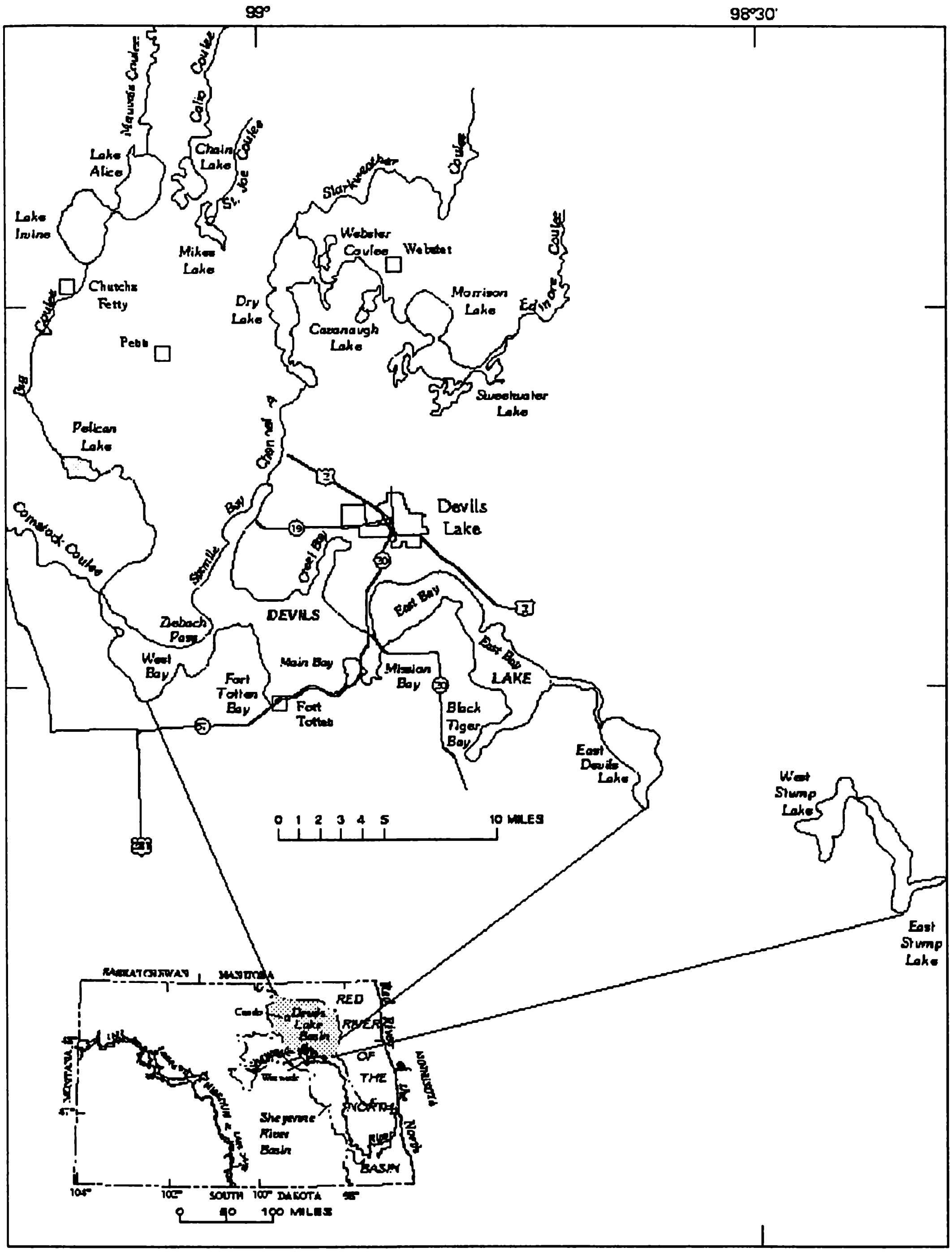


Figure 1. Location of the Devils Lake Basin.

1826 at 1,445 ft above sea level and continued for 65 years (until 1890). Only those simulations that met the constraints mentioned earlier were used. By repeating this procedure more than 200,000 times, a total of 200 possible historical sequences of lake levels and precipitation, evaporation, and inflow values were generated for 1826-90. Each sequence satisfied the lake-level constraints.

The lower and upper 5-percent bounds for the simulated lake levels are shown in figure 2. In any given year, only 5 percent (10) of the 200 generated lake levels were below the lower bound, and 5 percent were above the upper bound. The lower bound indicates that the lake level could have declined to about 1,425 ft above sea level in the 1850's, about a 20-ft decline in 30 years. This rate of decline is close to the actual rate of decline that occurred from 1867 to 1890 when the level declined about 14 ft in 24 years. The upper bound indicates that the lake level could have remained near 1,440 ft above sea level from 1826 to 1867, indicating a long period of relatively large inflows. The bounds on the lake level from 1867 to 1890 are much closer. Because net evaporation, the only significant mechanism causing lake-level declines, generally is between1 and 2 ft in any given year, the lake level could not have risen significantly between 1867 and 1890 and still declined to 1,424 ft above sea level in 1890.

To illustrate the hydrologic conditions that could have produced lake levels similar to those for 1826-90, total annual inflow values for each conditional simulation were smoothed by averaging values for 5 years. For example, the 5-year average annual inflow for 1864 is the average annual inflow to Devils Lake for the 5 years ending in 1864. Total annual precipitation values for Devils Lake also were smoothed to obtain 5-year average annual precipitation values for each sequence. The lower and upper 5-percent bounds on the simulated 5-year average annual inflow values and the bounds on the simulated 5-year average annual precipitation values are given in table 1. For comparison purposes, the known 5-year average annual inflow and precipitation values for a more recent dry period (1960-64) and a more recent wet period (1992-96) also are given in table 1.

Table 1. Conditional-simulation statistics for average annual inflow and precipitation values for Devils Lake

	5-year average annual inflow (acre-feet)			5-year average annual precipitation (inches)		
Year	Lower 5-percent bound	Median	Upper 5-percent bound	Lower 5-percent bound	Median	Upper 5-percent bound
1834	18,000	49,300	99,100	15.4	17.2	20.6
1839	23,200	57,000	134,200	15.1	17.8	20.6
1844	24,100	68,000	148,900	15.1	17.7	20.7
1849	23,300	66,400	158,000	15.0	17.6	20.3
1854	21,800	71,000	177,500	15.0	17.6	21.0
1859	27,800	86,400	191,500	14.8	18.1	21.0
1864	46,400	116,400	227,600	15.7	18.4	21.4
1869	33,100	90,800	212,700	15.6	18.0	21.6
1874	17,100	46,200	94,600	14.5	17.5	20.8
1879	16,200	46,000	97,900	14.9	17.1	20.3
1884	16,000	43,100	79,600	14.6	17.0	19.7
1889	17,400	37,600	78,600	14.3	17.3	20.2
[1]1964	12,400	12,400	12,400	16.8	16.8	16.8
[1]1996	238,200	238,200	238,200	20.6	20.6	20.6

[1]Known values.

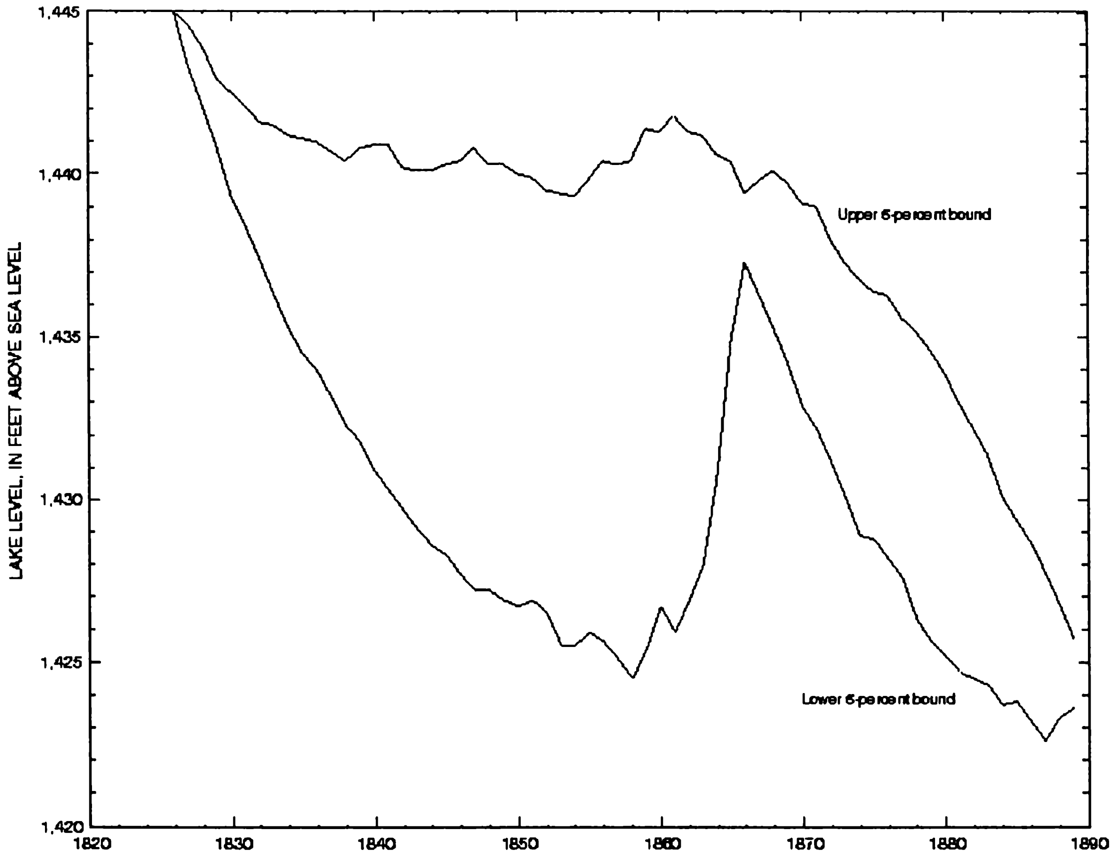


Figure 2. Lower and upper lake-level bounds for Devils Lake for 1826-90.

The large range in average annual inflow values (table 1) for any 5-year period, and especially for the 1850's and 1860's, is a result of the extreme variability of inflow to Devils Lake, which often has long periods of low or zero inflow followed by periods of one or more large inflows. More information is needed to determine whether the high lake level in 1867 was caused by a few very large inflows late in the period and low inflows early in the period or by generally large inflows over the entire period. The small changes in precipitation values (table1), on the order of a few tenths of an inch, are accompanied by large changes in inflow to Devils Lake. Thus, small variations in climatic conditions can cause large fluctuations in lake level, making Devils Lake ideal for studying the effects of long-term climate change.

The overall pattern shown in table 1 indicates that the most likely scenario is normal (compared to more recent data) precipitation and inflow in the 1830's, 1840's, and 1870's, above-normal precipitation and inflow in the 1850's and 1860's, and below-normal precipitation and inflow in the 1880's. The conditional simulation values were compared to the known values for a more recent dry period (1960-64) and a more recent wet period (1992-96). The average annual inflow [12,400 acre-feet (acre-ft)] for 1960-64 is much below the lower 5-percent bound for the conditional simulations, and the average annual precipitation [16.8 inches (in.)] for 1960-64 is below the median for the conditional simulations. The known average annual inflow (238,200 acre-ft) for 1992-96 is above the 5-percent bound for the conditional simulations, and the known average annual precipitation (20.6 in.) for 1992-96 is close to the upper 5-percent bound for the conditional simulations. Further research is needed to determine whether or not this indicates a climate change.

REFERENCES

1. Wiche, G.J. (1996) Lake levels, streamflow, and surface-water quality in the Devils Lake area, North Dakota. U.S. Geological Survey Fact Sheet FS-189-96, 4.
2. Wiche, G.J. and Vecchia, A.V. (1996) Lake-level frequency analysis for Devils Lake, North Dakota. U.S. Geological Survey Water-Supply Paper 2469, 57.
3. Upham, Warren (1895) The glacial Lake Agassiz. U.S. Geological Survey Monograph No. 25, 658.

IMPORTANCE OF BOTTOM-SEDIMENT PROCESSES TO MAJOR-ION AND NUTRIENT BUDGETS OF DEVILS LAKE, NORTH DAKOTA

Robert M. Lent*, U.S. Geological Survey, Water Resources Division, 28 Lord Road, Suite 280, Marlborough MA 01752
Gregg J. Wiche, U.S. Geological Survey, Water Resources Division, 821 East Interstate Avenue, Bismarck, ND 58501

INTRODUCTION

Devils Lake is a terminal lake in a large closed basin in northeastern North Dakota (fig. 1). As with other closed-basin lakes, fluctuations in the lake level and water chemistry of Devils Lake are closely related to variations in the climatic conditions in the drainage basin. Recent lake-level fluctuations, including decreasing lake levels during the late 1980's through the early 1990's and increasing lake levels since mid-1993, have resulted in economic hardship to residents of the Devils Lake Basin. Proposed plans to stabilize the lake level and ameliorate the recent problems related to periodic flooding and drought conditions are predicated on understanding the hydrologic and chemical budgets of the lake. The hydrology of Devils Lake is well documented (1, 2). Generally, inflow to the lake is from surface water and direct precipitation, and the only significant outflow from the lake is by evaporation. The chemical budget of the lake is more complicated, however. External inputs of chemical components include surface-water inflow and atmospheric deposition. Removal pathways generally are limited to aeolian transport of aerosols and desiccation salts and to burial of evaporitic minerals and saline pore water in the lakebed. The chemical budget of the lake is further complicated by internal cycling, which buffers the dissolved-solids concentration in the lake. The cycling is driven by complex biogeochemical processes that occur in the bottom sediments and include dissolution reactions and pore-water diffusion. Hydrologic investigations that characterize the hydrology, chemistry, and biology of Devils Lake since the mid-1980's have been conducted by the U.S. Geological Survey in cooperation with the U.S. Army Corps of Engineers, the North Dakota State Water Commission, the North Dakota Department of Health, and the North Dakota Game and Fish Department. The purpose of this paper is to present the results of those investigations in order to illustrate the importance of bottom-sediment processes to major-ion and nutrient budgets of Devils Lake.

DISCUSSION

Temporal variations in the concentration and mass of dissolved solids in closed-basin lakes generally are related to fluctuations in lake level (3). During dry periods, the lake level decreases, the dissolved-solids concentration increases, and the dissolved-solids mass decreases as a result of evaporitic concentration. During wet periods, the lake level increases, the dissolved-solids concentration decreases, and the dissolved-solids mass increases as a result of tributary inflow and precipitation. During periods of decreasing lake levels, some of the dissolved-solids mass is permanently lost by aeolian transport of desiccation salts or effectively lost by burial of evaporitic minerals and saline pore water. Therefore, the relation between the lake level and the dissolved-solids concentration is not constant (3). Variations in the concentration and mass of dissolved solids in Devils Lake follow this general pattern (4). Furthermore, dissolved-solids concentrations gradually increase during periods of stable lake levels, indicating an internal dissolved-solids source to Devils Lake.

Lent (5) used water-column profiles of specific conductance, pH, and dissolved-oxygen concentrations to examine potential effects of bottom-sediment processes on the water chemistry of Devils Lake. The samples were collected from July 1986 through October 1991. During ice-free periods, Devils Lake was well mixed. During the winter, however, bottom water generally had larger specific-conductance values, smaller pH values, and smaller dissolved-oxygen concentrations. The variations are attributed to microbially mediated sulfate reduction and mineral dissolution processes that occur in the bottom sediments of the lake (5). Although these processes probably occur throughout the year, water-column mixing by wind obscures their effect during ice-free periods.

During the summer of 1993, the Devils Lake Basin received unusually large amounts of precipitation that resulted in a substantial increase in surface-water runoff to the lake. Williams-Sether et al. (6) used changes in the masses of dissolved solids, total nitrogen, and total phosphorus during a 3-month period in 1993 to evaluate the effect of bottom-sediment processes on major-ion and nutrient mass balances during high-inflow conditions (table 1). During the 3-month period of increased inflow, the concentrations of dissolved solids, nitrogen, and phosphorus decreased, and the total masses increased. However, only about 30 percent of the increased masses of dissolved solids and nitrogen was attributed to surface-water inflow. During the same period, the increased mass of phosphorus in the lake was about equal to the mass of phosphorus contributed by surface water.

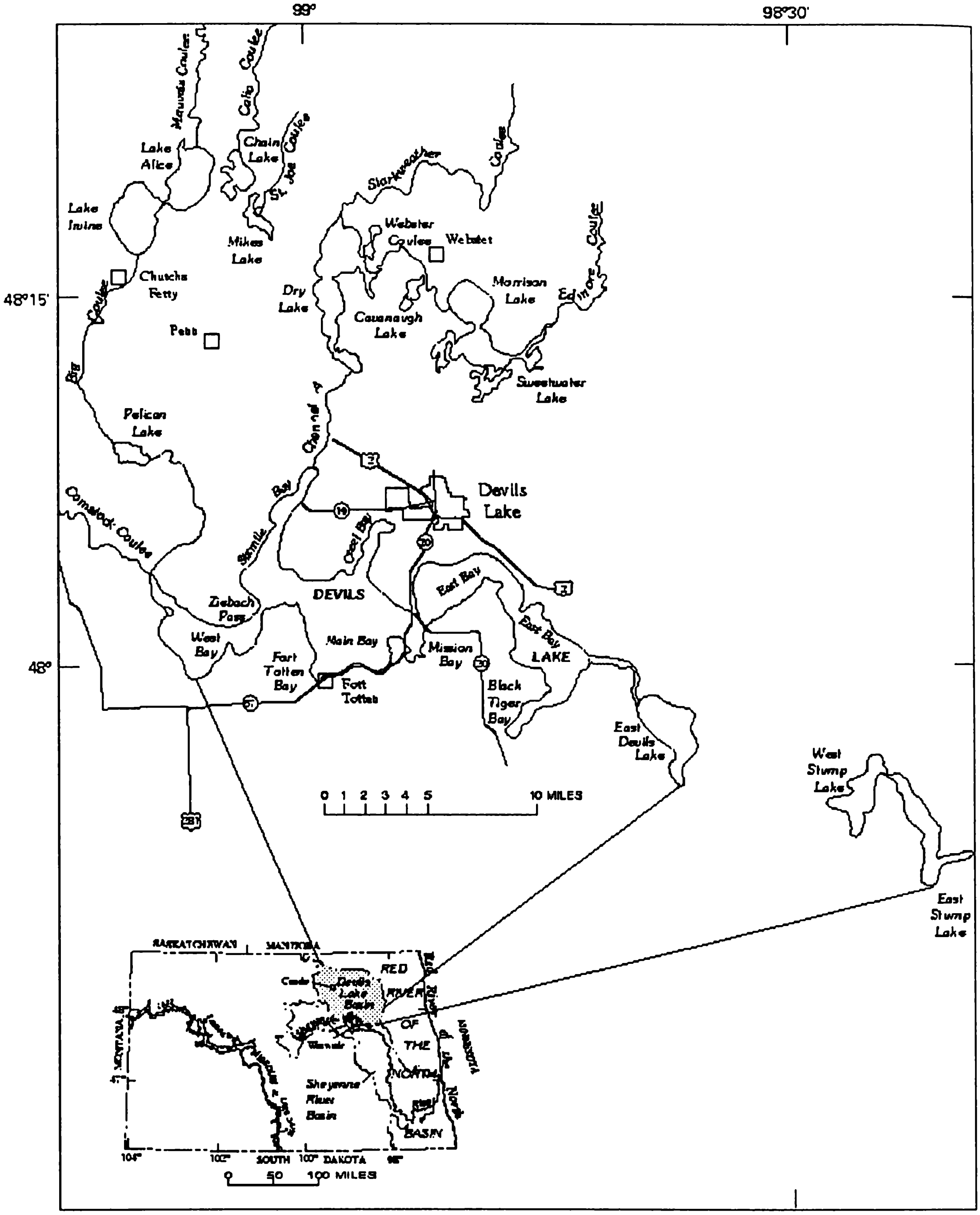


Figure 1. Location of the Devils Lake Basin.

Table 1. Cumulative dissolved-solids and nutrient loads in Big Coulee and Channel\x11A, April through October 1993, and dissolved-solids and nutrient masses in Devils Lake, May through October 1993

[Modified from Williams-Sether et al. (6); kg, kilograms]

	Dissolved solids (kg)	Nitrite plus nitrate, dissolved (kg as N)	Ammonia, dissolved (kg as N)	Ammonia plus organic nitrogen, total (kg as N)	Phosphorus, total (kg as P)	Orthophosphate dissolved (kg as P)
			Cumulative dissolved-solids and nutrient loads			
Big Coulee	44,500,000	17,400	7,870	83,000	37,400	35,400
Channel A	78,300,000	16,100	9,940	157,000	60,600	45,400
Total load attributed to tributary inflow	123,000,000	33,500	[1]17,800	240,000	98,000	80,800
			Dissolved-solids and nutrient masses			
05-11-93	4,200,000,000	109,000	71,100	2,170,000	110,000	53,000
10-21-93	4,700,000,000	109,000	177,000	3,000,000	197,000	100,000
Change in mass in Devils Lake	500,000,000	0	105,900	830,000	87,000	47,000
Total load attributed to tributary inflow divided by change in mass in Devils Lake	0.25	—	0.17	0.29	1.13	1.72

[1]Number has been rounded.

Table 2. Calculated pore-water benthic-flux rates in sediment cores collected from Creel Bay and Main Bay, Devils Lake, 1990-91

[Modified from Lent (5) and Komor (9); positive values indicate that the flux is from sediments into bottom water, and negative values indicate that the flux is from bottom water into sediments; flux rates are in milligrams per square meter per day; —, no data]

Constituent	Creel Bay, July 25, 1990	Main Bay, July 26, 1990	Main Bay, July 30, 1991	Main Bay, August 27, 1991	Main Bay, October 8, 1991
Calcium	16	6.7	12	5.2	5.6
Magnesium	14	14	31	15	12
Sodium	47	170	140	59	38
Potassium	38	38	24	—	4.1
Bicarbonate	3,300	2,500	470	810	440
Sulfide (as S)	110	27	51	43	24
Sulfate (as SO_4)	-1,000	-1,500	410	-260	240
Sulfur (as SO_4)[1]	-730	-1,400	560	-131	310
Chloride	130	35	110	110	32
Ammonia (as N)	26	130	9.0	7.1	7.1
Phosphate (as P)	3.9	2.9	9.8	.16	.24

[1]Calculated as the sum of sulfide and sulfate

Table 3. Calculated pore-water benthic-flux rates in sediment cores collected from East Bay, Devils Lake, 1986
[Modified from Lent and Lyons (8); positive values indicate that the flux is from sediments into bottom water, and negative values indicate that the flux is from bottom water into sediments; flux rates are in milligrams per square meter per day; — no data]

Constituent	Main Bay, 1991[1]	East Bay, Core 1	East Bay, Core 2	East Bay, Core 3	East Bay, Core 4
Calcium	7.6	10	14	250	390
Magnesium	19	27	24	320	160
Sodium	79	1,400	250	2,800	1,300
Potassium	14	660	39	430	220
Bicarbonate	570	220	260	420	240
Sulfate (as SO_4)	250	300	410	3,900	620
Ammonia (as N)	7.7	4.1	5.1	10	4.2
Phosphate (as P)	3.4	.31	.53	-34	-37

[1]Mean of samples collected on July 30, 1991; August 27, 1991; and October 8, 1991.

Table 4. Calculated major-ion and nutrient response times for Devils Lake (defined as Main Bay plus East Bay, Devils Lake) and for Main Bay, Devils Lake
[Modified from Lent (5)]

Constituent	Response time, Devils Lake (years)	Response time, Main Bay (years)
Calcium	6.7	63
Magnesium	32	95
Sodium	15	110
Potassium	8.1	76
Bicarbonate	13	9.6
Sulfate (as SO_4)	34	78
Total nitrogen (as N)	4.2	3.4
Total phosphorus (as P)	.95	.46

In recent studies by Lent (6), Komor (7), and Lent and Lyons (8), pore-water data were used to quantify major-ion and nutrient benthic-flux rates in bottom sediments of Devils Lake. Komor (7) collected sediment cores for pore-water analysis in July 1990, and Lent (5) collected four additional sediment cores from May to October 1991. The cores were collected from Creel Bay and Main Bay, Devils Lake. Seasonal variations in the benthic-flux rates generally were small (table 2), but important differences existed between the calculated benthic-flux rates for 1990 and the calculated benthic-flux rates for 1991. Benthic-flux rates for bicarbonate, ammonia, and phosphate generally were smaller in 1991 than in 1990. Lent (5) attributed the large differences to calm, stratified water-column conditions in 1990 and well-mixed water-column conditions in 1991. Lent and Lyons (8) collected four cores from East Bay, Devils Lake, during 1986 and compared the benthic-flux rates for those cores to the rates for cores collected from Main Bay (table 3). Sediment pore water in East Bay had larger major-ion benthic-flux rates than sediment pore water in Main Bay, but sediment pore water in Main Bay generally had significantly larger nutrient benthic-flux rates. The major-ion concentrations in pore water and the benthic-flux rates increase from west to east, indicating that bottom-sediment processes may be partly responsible for the concentration gradient in the lake.

The relative importance of benthic fluxes to the chemical mass balances of major ions and nutrients in Devils Lake was evaluated by calculating major-ion and nutrient response times for Devils Lake (table 4). The response time is an estimate of the time needed to replace the mass of a constituent in the lake. The calculated major-ion response times for Devils Lake ranged from 6.7 years for calcium to 34 years for sulfate. The response times are significantly smaller than previous estimates, which did not include benthic fluxes. In addition, the relatively short response times for nitrogen (4.2 years) and phosphorus (0.95 year) indicate that nutrients are recycled rapidly between bottom sediments and the lake. Although benthic fluxes may cause underestimated response times at different lake levels, the fluxes can be dominant sources of major ions and nutrients to Devils Lake. Therefore, bottom-sediment processes may buffer the major-ion and nutrient concentrations in the lake.

REFERENCES

1. Wiche, G.J. (1992) Hydrology and water-level fluctua tions of Devils Lake, North Dakota—Selected Papers in the Hydrologic Sciences 1988-92. U.S. Geological Survey Water-Supply Paper 2340, 75-87.
2. Wiche, G.J. and Vecchia, A.V. (1996) Lake-level frequency analysis for Devils Lake, North Dakota. U.S. Geological Survey Water-Supply Paper 2469, 57.
3. Langbien W.B. (1961) Salinity and hydrology of closed lakes. U.S. Geological Survey Professional Paper 412, 20.
4. Sando, S.K. and Lent, R.M. (1995) Spatial and seasonal variability in water quality of Devils Lake, North Dakota, September 1988 through October 1990. U.S. Geological Survey Water-Resources Investigations Report 95-4081, 41.
5. Lent R.M. (1994) Sources and cycling of major ions and nutrients in Devils Lake, North Dakota. U.S. Geological Survey Water-Resources Investigations Report 94-4171, 63.
6. Williams-Sether, T., Lent, R.M., and Wiche, G.J. (1996) Variations in surface-water quantity and quality as a result of the 1993 summer flood in the Devils Lake Basin, North Dakota. U.S. Geological Survey Water-Resources Investigations Report 96-4028, 32.
7. Komor, S.C. (1992) Bidirectional sulfate diffusion in saline-lake sediments—Evidence from Devils Lake, northeastern North Dakota. Geol\x1120, 319-322.
8. Lent, R.M. and Lyons, W.B. (1995) Pore-water geochemistry and solute flux from bottom sediments, Devils Lake, North Dakota. Internat Jour of Salt Lakes Res 3, 113-135.
9. Komor, S.C. (1994) Bottom sediment chemistry in Devils Lake, northeast North Dakota, in Sedimentology and Geochemistry of Modern and Ancient Saline Lakes (Renaut, R. and Last, W.M., eds). Soc of Environmental Petrologists and Mineralogists Special Pub No 50, 21-32.

DEVILS LAKE BASIN UPPER BASIN FLOOD STORAGE POTENTIAL

Lee Klapprodt*
North Dakota State Water Commission, 900 E. Blvd., Bismarck, ND 58505

INTRODUCTION

Background

The Devils Lake basin has been for many years a closed sub-basin of the Red River of the North with Devils Lake being the terminal lake in this basin. The basin covers about 3,810 square miles in northeastern North Dakota. In the 130 years since the first official measurement, Devils Lake's water levels have varied from 1438.4 feet above mean sea level (amsl) in 1867 to a low of 1400.9 feet amsl in 1940. The lake now exceeds elevation 1437.8 feet amsl.

Since reaching its recorded low, Devils Lake's water level has followed a rising trend. In July of 1993, Devils Lake covered an area of about 46,000 acres. Wet climatic conditions have resulted in a continued rise. A flood forecast made by the U.S. Weather Service on February 14, 1997 predicts the lake may reach elevation 1440.5 feet amsl in 1997. At that elevation, Devils Lake will cover about 87,600 acres, nearly twice the land area covered four years earlier.

Topography across much of the Devils Lake basin is rolling glacial plain characterized by many shallow wetlands and a few smaller lakes. Devils Lake and Stump Lake are at the southern-end of the drainage system. A chain of smaller lakes is located in the system just above Devils Lake. The drainage system includes several coulees that generally flow from north to south and through the chain of lakes upstream of Devils Lake. About 87 percent of the drainage basin is tributary to Devils Lake, with the remaining 13 percent tributary to Stump Lake.

Problem to be addressed

Until 1979, flood damage concerns in the basin were limited to the effects on agriculture. Spring runoff in 1979 caused the lake to rise from 1423.2 feet amsl to 1427.0 feet amsl. Several sections of highway were flooded and the first affects were felt at the City of Devils Lake. Local, state and federal agencies responded by raising some roads and constructing a levee to protect the City of Devils Lake against a lake elevation up to 1440 feet amsl. Despite these precautions, flood damages experienced since 1993 total about $100 million. The North Dakota State Water Commission (SWC) estimates the forecasted 1997 rise will cause about $30 million in new damages.

Total volume of water in Devils Lake has increased from about 581,000 acre-feet (ac-ft) in July of 1993 to about 1.5 million ac-ft in August of 1996. An additional 160,000 ac-ft of water or more is predicted to enter the lake from spring runoff in 1997 raising it more than 2 feet. Until the lake rises to its natural outlet elevation of 1,457.5 feet amsl, runoff from contributing parts of the basin will increase the lake level and add to flood damages. One method to combat flooding around Devils Lake is to retain runoff water in the upper basin.

Upper basin flood storage concept

Basin land use is about 70 to 80 percent agricultural. Tillage practices have included artificial drainage of many shallow depressions or wetlands. Debate between various interest groups has raged for years concerning the effects of drainage on flooding and the volume of water storage available through wetland restoration. Several attempts have been made to quantify the number of wetlands drained and the impact on runoff characteristics in the basin. None has reached a consensus.

In June 1996, the Devils Lake Basin Joint Water Resource Board and the National Wildlife Federation posed questions about the impact of drainage to state and federal natural resource agencies. The question most pertinent to this study is: "How much water storage volume is possible in the upper Devils Lake Basin?"

After conferring with the other agencies, the SWC and the U.S. Fish and Wildlife Service (USFWS) assumed a lead role in developing a new estimate of available storage.

STUDY METHODS

Scoping the study process

The study objective was to provide an estimate of potential storage available in the Devils Lake basin. Due to the limited time and budget, it was necessary to rely almost entirely on existing information to meet study objectives.

The approach to meet study objectives included:

- establishing a study team,
- data inventory and development,
- identification and assessment of available tools and methodologies,
- field testing,
- application of methodologies, and
- reporting.

Study team

The agencies formed a study team led by Stan Hanson, an employee of the SWC and Bill Pearson, an employee of the

USFWS. Other study team participants included representatives from the U.S. Natural Resource and Conservation Service (USNRCS) and U.S. Geological Survey (USGS).

Data development

Study participants agreed early in the process that the small lakes located upstream from Devils Lake and drained and partly drained wetlands offered the most potential for new or restored water storage in the Devils Lake basin. Storage below the normal operating levels of small lakes and the storage in non-drained wetlands was considered as existing storage. This direction focused the study team efforts.

Wetland drainage in the Devils Lake basin has never been completely inventoried due to the large area involved. A 1983 study by Ludden, et al. (1) faced the same problem. Their analysis built upon data collected from randomly selected quarter-section sample areas that were originally part of the Department of Agriculture's Conservation Needs Inventory (2). The study team chose to use a similar approach. Instead of quarter sections, data was developed for full, 640-acre sections. The sample sites involved 207 sections, totaling 132,141 acres, or about 5.4 percent of basin area.

NWI derived drained and partly drained wetlands

The most comprehensive wetland data for the Devils Lake basin is the National Wetland Inventory (NWI). While these data provide significant detail in mapping and classification of wetlands, the inventory did not include drained wetlands. Completely drained wetlands do not meet the criteria for wetland defined by "Classification of Wetlands and Deepwater Habitats of the United States," Cowardin et al. (4), so they were not inventoried. This shortcoming required the study team to revisit the original color infrared photography used in the NWI. The NWI did inventory the remaining portions of partly drained wetlands because they retained some wetland characteristics. The study team included mapping of the portion of partly drained wetlands not included in the NWI.

Most of the basin's NWI aerial photography was obtained in 1979. However, some small areas within the basin were re-flown as late as 1983. This photography was photo-interpreted to map drained wetlands and the original area of partly drained wetlands on the sample sections. Photo signatures, showing soil moisture differences and cultivation practices, coupled with physical features such as topographical depressions and linear drainage ditches, were used to identify drained and partly drained wetlands. Collateral data such as, County Soil Surveys; USGS, 7.5 minute topographic maps, USNRCS National Resource Inventory wetland delineations, and the 1":800' scale black and white photography used in the Ludden, et al. (1) study, were used to assist in delineating drained wetlands. Maps produced by photo-interpretation were geometrically corrected, copied to mylar and digitized for use in a geographic information system (GIS).

Field testing

Study team members, local water managers and local agricultural producers visited the first sample sites mapped to assess photo-interpretation accuracy. While subjective, this process confirmed that the interpretation coincided satisfactorily with what was on-the-ground.

Mapping technology

The study team chose to use MapInfo GIS software to analyze existing NWI and newly developed drained and partly drained wetland data. MapInfo enabled production of two-dimensional maps yielding the number, location and acreage of drained and partly drained wetlands on the sample sites. Data derived for the sample sites were then expanded at a ratio equal to the total basin area divided by the total sample site area, 18.47 to1. A statistical analysis showed this to be a satisfactory approach for this study due to the large number of sample sites.

Drainage not include in NWI data

Wetland drainage probably continued between acquisition of the NWI aerial photography and the advent of Swampbuster provisions in the 1985 Farm Bill. It was agreed that very little drainage has occurred in the basin since Swampbuster took effect. The study team used the USFWS' Private Drainage Survey done between 1966 and 1980 to estimate the amount of wetland drainage since the NWI aerial photography was collected. That survey showed the rate of drainage in the Devils Lake region to be 2.5 percent per year.

Small lake potential storage

Prior to this study, the SWC investigated the storage potential available in small lakes located upstream of Devils Lake. After reviewing these figures, the storage estimates were adopted by the study team. The investigation found that additional water storage is available at the small lakes if controls could be built to increase the operating levels.

Conversion of acre data to acre-feet of storage

Determining the volume of storage available on the mapped drained and partly drained wetland areas was the most difficult aspect of this study. The amount of water stored in a wetland basin varies from year to year, depending on the amount of runoff. This situation caused the study team to use two analysis methods, one developed by Best (3) and the other by Ludden et al. (1). These studies documented that a ten-year frequency runoff event would produce about one ac-ft of water per acre in the region's wetlands. A ten-year runoff event will not fill every wetland to its overflow level, its maximum storage potential. A 100-year frequency or greater event may be required to fill all wetlands to their overflow level. This study developed information that represents an estimate of the maximum storage potential of Devils Lake basin wetlands.

RESULTS

Storage potential using NWI data

Re-analysis of NWI aerial photography and GIS techniques mapped a total of 1,079 drained and 1,508 partly drained wetlands on the study's 207 sample sites.

Expanding the photo-interpreted data for the entire Devils Lake basin results in a conservative estimate of 25,940 acres of drained and 34,000 acres of partly drained wetlands at the time of the photography, 1979-1983. Total restorable wetland acres identified in this study is an estimated 60,000 acres.

Calculating the maximum water storage potential in 60,000 acres of drained wetland basins, using methods developed by Best (3) and Ludden et al. (1), produces a range of 156,000 to 294,000 ac-ft.

Wetlands acres drained between 1980 and 1985

The study team used a combination of NWI and the Private Drainage Survey data to determine the number of wetland acres drained after the NWI survey. Analysis of NWI data showed 252,000 acres of wetland remained intact in the Devils Lake basin. Applying a 2.5 percent annual drainage rate, 41,000 wetland acres may have been drained between 1980 and 1985. Because these drained wetlands were not mappable, it was impossible to apply the methods developed by Best (3) and Ludden et al. (1). However, assuming a ten-year event, restoring these wetlands would provide another 41,000 ac-ft of water storage.

Upper basin lakes storage

The State Water Commission developed information on the current holding levels of the small lakes located upstream of Devils Lake. A total of 33,250 ac-ft of water storage is available by raising current operating levels from one to three feet. An estimated 8,700 acres of riparian land would be inundated.

Report to Devils Lake Joint Water Resource Board and National Wildlife Federation

At the conclusion of the study, the U.S. Army Corps of Engineer (St. Paul District), USNRCS, U.S. Environment Protection Agency, U.S. Bureau of Reclamation, USFWS, SWC, and the USGS reviewed and commented on the study findings before completion of the final report.

On January 8, 1997, the North Dakota State Engineer and U.S. Fish and Wildlife Service jointly signed a letter reporting the study findings to the Devils Lake Joint Water Resource Board and the National Wildlife Federation. The letter provided the storage estimates reported in this paper and concluded that substantial restorable storage exists within the Devils Lake basin.

REFERENCES

1. Ludden,A.P., Frink,D.L.and Johnson,D.H.(1983) J. Soil & Water Conservation, Volume 38. Number 1, pp 45-48.

2. U.S. Soil Conservation Service.(1979) North Dakota Conservation Needs Inventory. Bismarck, North Dakota.

3. Best,R.G.(1978)Pecora IV Symposium Proc., Application of Remote Sensing Data to Wildlife Management, Sioux Falls, South Dakota, October 10-12, pp 180-187.

4. Cowardin,L.M., Carter,V., Golet,F.C. and LaRoe, E.T.(1979) Classification of Wetlands and Deepwater Habitats of the United States, U. S. Depart. Interior. 131pp.

DEVILS LAKE EMERGENCY OUTLET PLAN (EOP)

Todd Sando*, P.E.
North Dakota State Water Commission, 900 East Boulevard Avenue, Bismarck, ND 58505

I. INTRODUCTION

Devils Lake is the largest natural lake in North Dakota. Known as North Dakota's finest natural jewel, Devils Lake is unique in that it is trapped within its basin by its topography. This uniqueness is only comparable to the Great Salt Lake in Utah.

Devils Lake is the ultimate collecting point for the majority of the Devils Lake basin's 3,800 square mile watershed. The amount of runoff entering the lake is determined by a complicated set of circumstances which result in widely fluctuating lake levels. Since the retreat of the glaciers, the water level of Devils Lake has fluctuated from about 1457.5 feet msl (which is the approximate elevation that Devils Lake discharges water to the Sheyenne River) to about 1400 feet msl. The level of Devils Lake is currently at 1437.8 feet msl. This is only slightly below its recorded peak elevation of 1438.4 feet msl in 1867. Based on winter snowpack and the potential for significant runoff, the North Dakota State Water Commission (Commission) believes the lake will rise above its 1867 peak, possibly into the 1440 feet msl range. At elevation 1440 feet msl, Devils Lake covers 87,600 acres. In the spring of 1993, Devils Lake had 45,500 surface acres. This increase has had drastic impacts on ranchers, homeowners, cabin owners, developers, city and county governments, utilities, and roads.

In response to the problems in the Devils Lake basin, the Commission has dedicated extensive employee hours. We have implemented an Available Storage Assistance Program (ASAP) to increase water storage in the upper basin. We have looked at many outlet alignments and types of outlets including pipelines, open channels, and gravity flow tunnels. We have also looked at many intra-basin options, such as an outlet to Stump Lake, road raises, and a Ziebach Pass dam and closure.

This paper discusses a potential implementation of the Devils Lake Emergency Outlet Plan (EOP) (1) to the Sheyenne River to alleviate ongoing flooding problems. A water project of this magnitude has many issues. Engineering design of an outlet, though complicated, is technically and economically feasible and is probably the least difficult aspect of the project. Other aspects of the project, which are more difficult and controversial, include social, environmental, cultural impacts, and permitting. The Commission, U.S. Army Corps of Engineers, and other agencies have been involved in emergency outlet planning with the objective to develop a project that is acceptable to people within the basin as well as those downstream. Several meetings have been held and more will be held with Canadian officials, Minnesota state officials, the Devils Lake Spirit Lake Nation, and individuals and groups along the Sheyenne and Red Rivers.

II. OUTLET ENGINEERING FEASIBILITY

Due to the complexity of the issues, this paper concentrates on the outlet engineering design which includes the location, size, outlet configuration, cost, timeline, and effectiveness. It will not attempt to address the larger challenges relating to social, political, international, tribal, and environmental concerns. The Corps of Engineers, the lead agency for this project, with assistance from the Commission, developed the EOP. The proposed plan will comply with the National Environmental Policy Act, Clean Water Act, Endangered Species Act, and the Boundary Waters Treaty of 1909. As of February 1997, federal and state agencies are waiting for authorization and funding to move forward with project implementation.

The selection of the EOP's design was based on numerous criteria including location, size, costs, right-of-way, environmental and cultural concerns, water quality, acceptability to downstream interests, effectiveness, permits, and construction time.

A. LOCATION

Many outlet locations were evaluated. Alignments evaluated included Peterson Coulee alignment and Twin Lakes alignment from the West Bay, Fort Totten alignment from the Main Bay, Mission Bay alignment, Black Tiger Bay alignment from the East Bay, East Devils Lake alignment; and East Devils Lake to Stump Lake alignment with various outlet alignments from either West Stump Lake or East Stump Lake. Another option is to reroute inflows around Devils Lake directly to the Sheyenne River. Figure 1 shows possible alignments.

The alignment selection is dictated by Devils Lake water quality concerns. Total dissolved solids (TDS), a measure of salinity, is the major water quality concern. Other water quality parameters of concern include mercury, arsenic, and downstream nutrient loading from the outlet because of nutrient rich hypereutrophic conditions of Devils Lake. All water quality parameters including anions, cations, heavy metals, pesticides, etc., are being addressed.

Devils Lake is a terminal lake and is highly saline, like the Great Salt Lake. As lake water evaporates, minerals dissolved in the water remain in the lake continually increasing the concentration. This process is the reason why Devils Lake contains large amounts of dissolved salts and high concentrations of other nutrients and minerals. Devils Lake salinity levels are significantly higher than the receiving waters of the Sheyenne River. Devils Lake consists of several large bays. These bays have significantly different TDS concentrations. The following table shows the west to east increase in salinity levels in Devils Lake.

TDS & SULFATE CONCENTRATIONS (October 1, 1996)

LOCATION	TDS MG/L	SULFATES MG/L
West Bay (South of Road)	1140	494
Main	1490	645
East Bay	2430	952
East Devils Lake	6770	3670

The salinity is lower in the west end of the lake because the majority of the fresh water enters here. The primary inlets to Devils Lake are Big (Mauvais) Coulee, which enters the West Bay, and Channel A, which enters the Main Bay. These two inlets have essentially the same water chemistry as is found in the Sheyenne River. Therefore, if inflows were rerouted around Devils Lake to the Sheyenne River water quality would not be an issue. Once water enters Devils Lake, these water quality concentrations are increased by mixing with lake water causing a significant water quality issue for the receiving waters.

Although rerouting inflows around Devils Lake sounds like an appropriate solution, there are several major drawbacks. These drawbacks include the high cost of implementation, the future viability of the Devils Lake fishery, the upper Sheyenne River's limited channel capacity, and the similar timing of the rerouted Devils Lake inflows and the high flows on the Sheyenne River. Based on these concerns this option is not recommended.

The water quality standards and objectives set by the North Dakota State Department of Health for the receiving waters dictate that the outlet needs to remove the best quality water possible from Devils Lake. The following table illustrates these standards and objectives. There are no standards for TDS on the Sheyenne, but there are for sulfates which are a component of TDS.

WATER QUALITY STANDARDS & OBJECTIVES

Location	TDS	Sulfate
Sheyenne River	None	450 mg/l
Red River of North	500 mg/l	250 mg/l
International objectives at U.S./Canada border	500 mg/l	250 mg/l

Alignments were narrowed down to the Twin Lakes and Peterson Coulee alignments from the West Bay of Devils Lake because of water quality concerns. The topography along the Twin Lakes is approximately 50 feet lower at the divide than Peterson Coulee alignment. This elevation difference reduces the initial costs of construction and the operating costs for the Twin Lakes alignment. Based on the lower costs, the Twin Lakes alignment was selected.

B. SIZE

The size of an outlet from Devils Lake is also dictated by water quality. The other parameter influencing the size is the Sheyenne River's channel capacity. During development of the EOP, the Sheyenne River's bank full channel capacity was estimated to be 500 cfs.

Sulfate loadings will be highest in the upper reaches of the Sheyenne River, where flows are lower, allowing only limited dilution. Sulfate loadings will attenuate as outlet water mixes with downstream inflows. Once water enters Lake Ashtabula, the sulfate loading will decrease significantly. Changes in the sulfate concentrations, in the lower Sheyenne River, will basically be the same as Lake Ashtabula. Once outlet water reaches the higher flows of the Red River, the impact on concentrations are minimal and within the more stringent standards of 250 mg/l.

In order to release water from Devils Lake and stay within sulfate standards, outlet water will need to mix with sufficient Sheyenne River flows. At times, releases will have to be reduced to meet water quality standards. For example, if the Sheyenne River is practically dry with a minimal flow of 10 cfs the Devils Lake outlet will not be able to release 200 cfs and will be reduced significantly. It is necessary to have good quality Sheyenne River water available to mix with the highly saline Devils Lake water. Without the availability of Sheyenne River water to mix with Devils Lake water, the Devils Lake outlet cannot be used. Therefore, it is important to have water in the Sheyenne River but not too high so that Devils Lake water will cause the Sheyenne River to exceed its channel capacity.

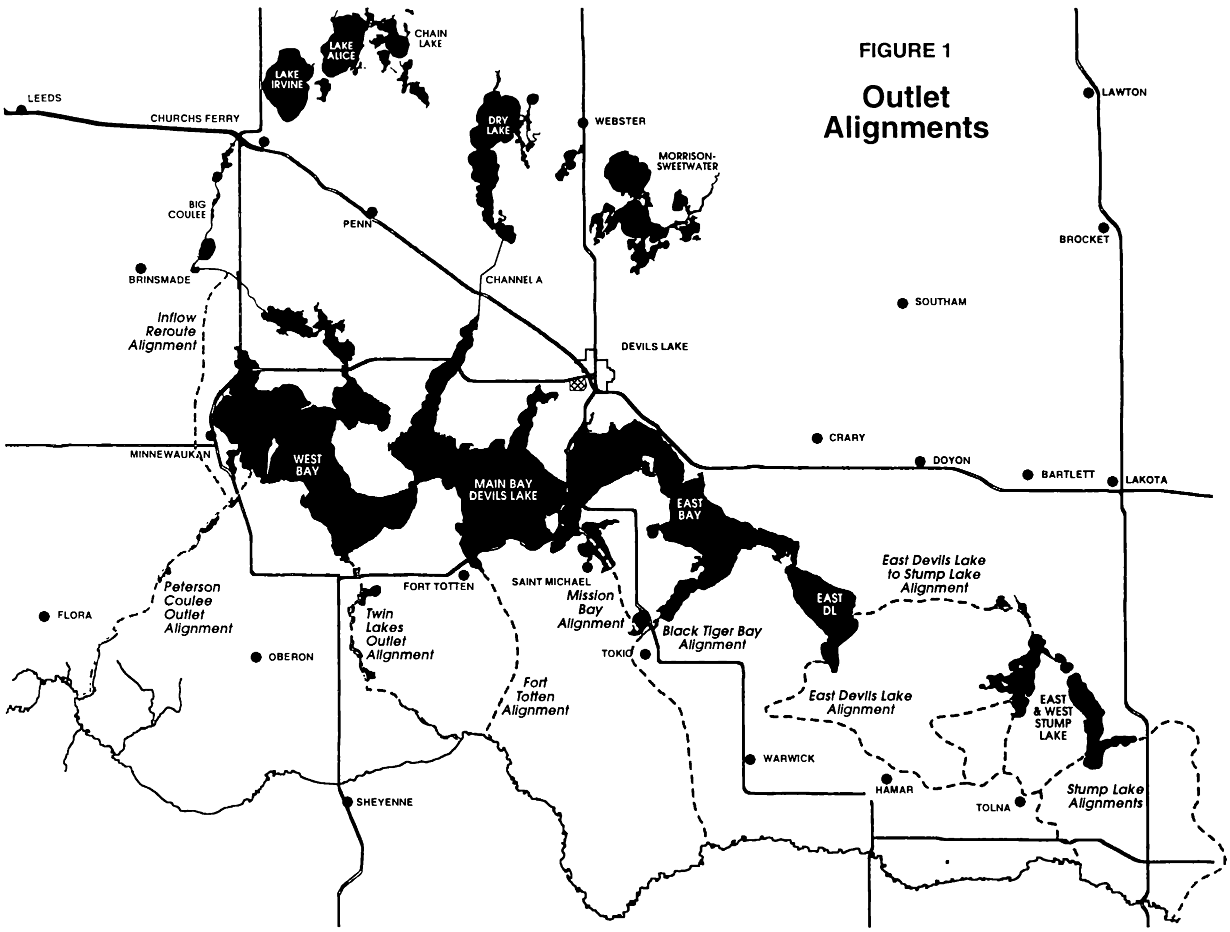
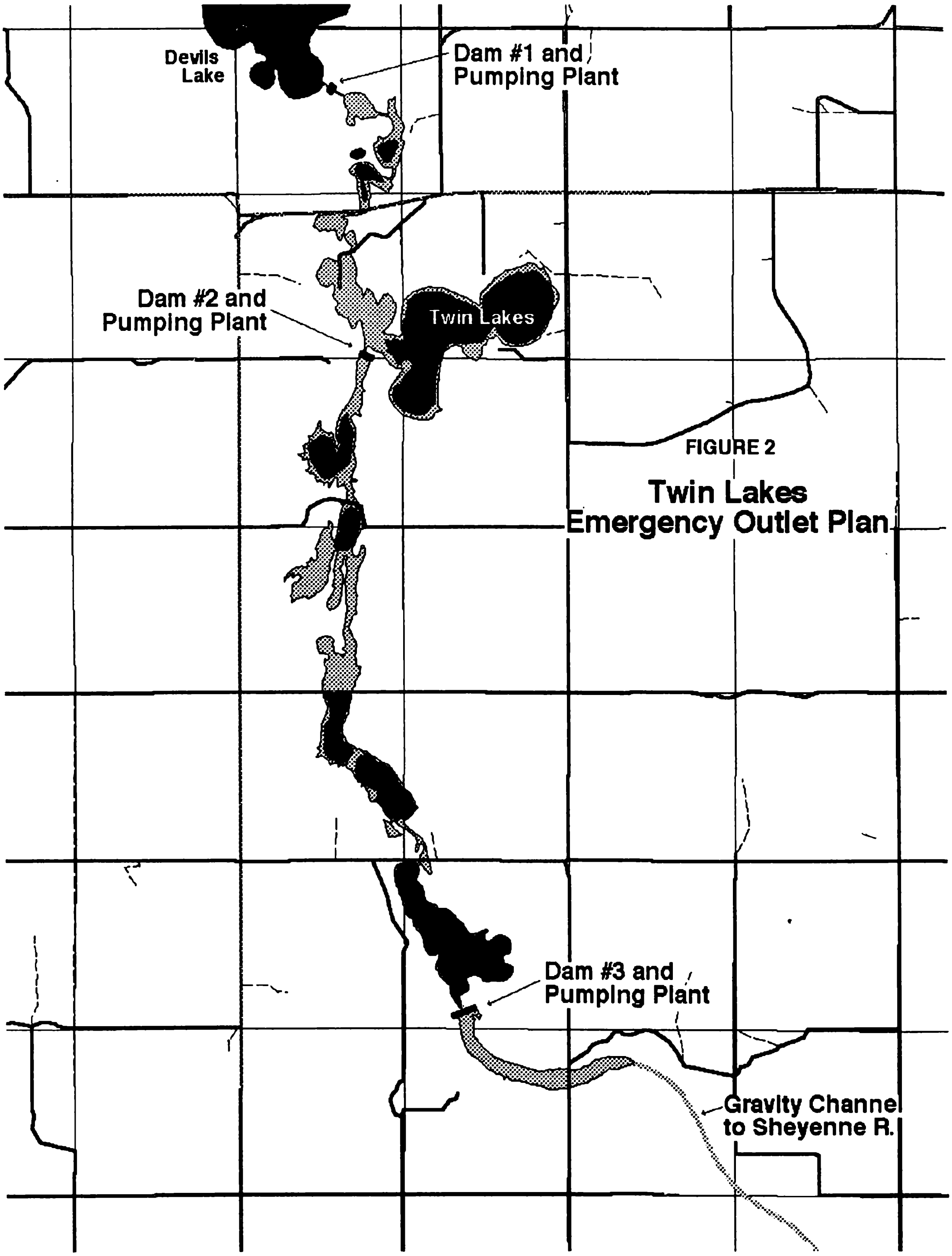


FIGURE 1
Outlet Alignments
LEEDS
CHURCHS FERRY
LAKE IRVINE
LAKE ALICE
CHAIN LAKE
DRY LAKE
WEBSTER
MORRISON-SWEETWATER
LAWTON
BIG COULEE
PENN
BRINSMADE
CHANNEL A
BROCKET
SOUTHAM
Inflow Reroute Alignment
DEVILS LAKE
MINNEWAUKAN
WEST BAY
MAIN BAY DEVILS LAKE
EAST BAY
CRARY
DOYON
BARTLETT
LAKOTA
FORT TOTTEN
SAINT MICHAEL
Peterson Coulee Outlet Alignment
FLORA
Twin Lakes Outlet Alignment
OBERON
Mission Bay Alignment
Black Tiger Bay Alignment
TOKIO
East Devils Lake to Stump Lake Alignment
EAST DL
Fort Totten Alignment
East Devils Lake Alignment
EAST & WEST STUMP LAKE
WARWICK
HAMAR
TOLNA
Stump Lake Alignments
SHEYENNE


Devils Lake
Dam #1 and Pumping Plant
Dam #2 and Pumping Plant
Twin Lakes
FIGURE 2
Twin Lakes Emergency Outlet Plan
Dam #3 and Pumping Plant
Gravity Channel to Sheyenne R.

The abrupt change in sulfate concentrations where Devils Lake water enters the Sheyenne River dictates that the outlet should be designed for only 200 cfs. Larger outlet capacities were evaluated up to 600 cfs, but due to water quality constraints it was not economical to make the outlet larger for the minimal amount of time it could be operated at a rate greater than 200 cfs.

C. OUTLET CONFIGURATION

The pumped storage/open channel combination, known as the EOP, was selected after evaluating several configurations, which included a pipeline/open channel combination, a pumped storage/open channel combination, and an open channel gravity outlet. The Twin Lakes Pumped Storage Plan involves moving excess Devils Lake water approximately 13 miles over the divide between Devils Lake and the Sheyenne River. The selected plan involves pumping lake water up into a series of three pools created by earth filled dams. The pools act like a ladder to effectively raise the water over the divide. At that point, the water flows down to the Sheyenne River in an open channel. Figure 2 shows outlet plan features.

Operation of the outlet will be limited to a 7-month period (May 1 through November 30) to prevent ice damage to the pumps and to avoid adding flow to the Sheyenne River during spring runoff. Within this 7-month period, operation will be restricted by downstream channel capacity and the 450 mg/l sulfate standard for the Sheyenne River. Operation would also be suspended when any portion of the Sheyenne River is threatened by flooding.

D. EFFECTIVENESS

Project effectiveness is limited due to channel capacity and water quality constraints in the Sheyenne River. Inflows during flood events at Devils Lake are significantly higher. An inflow of 3000 cfs is not uncommon. At times, inflows could be 15 times greater than EOP's design capacity. Thus, the lake would rise in response to these events. The goal is to dampen the flood event initially and then draw the lake down to a nonthreatening elevation after the event is over. In one year (210 pumping days) at full capacity operation of the outlet, 84,000 acre-feet of water would be removed from Devils Lake, which would lower the lake level approximately one foot. In an average year net evaporation removes approximately one foot of water from the lake. Therefore, if the outlet operated at full capacity (210 days) in an average year, the lake level could be reduced by two feet.

Lake Ashtabula and the communities of Warwick, Cooperstown, Valley City, Lisbon, Kindred, and West Fargo will be affected by the increased flows on the Sheyenne River. Some of the communities affected on the Red River include Halstad, Minnesota, Grand Forks, and Emerson, Manitoba. Mitigation of the increased treatment costs, due to increased sulfate loadings and other water quality parameters during outlet operations, may be needed. Such effects may persist after operation of outlet ceases.

E. COST

The estimated first costs, including planning, engineering, design, construction management, real estate, quantifiable environmental mitigation, and construction, are estimated to be \$21 million. Estimated annual operation and maintenance costs are \$700,00 per year for a 7-month operation (with operation suspended for the winter) and approximately \$200,000 per year when the project is not pumping.

F. TIME LINE

There are two implementation scenarios. Scenario one is a fast-tracked 29-month schedule, which assumes specific Congressional emergency authorization and appropriations. Scenario two is a 60-month timeline assuming that activities are accelerated, but with normal authorization and appropriations. Both timelines depend on close cooperation between federal and state agencies, the Spirit Lake Nation, and other local interests. Timelines will also depend on timely authority and funding, no real estate delays, and no litigation.

III. CONCLUSION

The EOP is one part of a three-pronged response to the Devils Lake flooding situation. The EOP is not the total answer to flooding at Devils Lake. A 200 cfs outlet could remove 84,000 acre-feet per year if not constrained by water quality concerns and the receiving waters channel capacity. It will take several years of operation to have a significant effect on lake levels. The second part is to continue to implement upper basin storage to store flood waters. The third part is to continue to address the immediate needs of the floodplain around Devils Lake, including the efforts to raise the levee to protect the city of Devils Lake, flood insurance, FEMA mitigation for relocations of structures, road raises and other remedial and preventive measures.

---

1. U.S. Army Corps of Engineers St. Paul District (1996) Emergency Outlet Plan Devils Lake, North Dakota.

THE HUMAN-ECONOMIC ASPECT OF THE DEVILS LAKE BASIN

Dr. Lowell R. Goodman*
Kirk Jensen
Department of Geography, University of North Dakota
Grand Forks, ND 58202-9020

TRADE AREA

The Devils Lake basin is similar to the general trade area. Reilly's break-point formula is used to identify Devils Lake's trade hinterland among several competing cities, Grand Forks, Fargo, Minot, Valley City, Jamestown and Bismarck, to form the Devils Lake trade area map (Fig. 1). The break point, or 50% shopper propensity line, is the critical line.

POPULATION FACTORS

Population data were compiled from 1950 to 1990 for the city of Devils Lake and the Devils Lake trade area. After the formulation of population data into different age cohorts for these two areas, the population dilemma facing the economy of Devils Lake was evident.

From 1970 to 1990 the population in Devils Lake's trade area, excluding the city itself, declined. Meanwhile, the population of the city had a slight gain from 7,078[1] people in 1970 to 7,782[2] in 1990 (Fig. 2). The decline in population of the trade area, excluding Devils Lake, is from 33,965 in 1970 to 26,996 in 1990. The principal reason for the gain in Devils Lake's population is that it is a focal point for older age cohorts in Devils Lake's rural trade area.

The population age cohorts in the Devils Lake trade area, excluding the city of Devils Lake, reveal a stairway appearance throughout the past forty years, with the younger age cohorts declining in population and the 65 and over age cohort rising.

The population age cohorts for the city of Devils Lake from 1950 to 1990 reveal how steady, percentage wise, the populations in the 5-19, 20-39, and 40-64 age cohorts have remained throughout this period (Fig. 3). However, the number of people in the 65 and over age cohort has increased steadily during this same period. Again, the reason for the increase in numbers in the 65 and over age cohort is the migration of this age group into Devils Lake.

The population in the rural region of Devils Lake's trade area will continue to decline, but the older age cohorts will continue to grow, especially in the city of Devils Lake where it may eventually take over as the leading age cohort in that community. When the older people begin to die and the younger people continue to leave for job opportunities, Devils Lake will have a serious negative population problem.

ECONOMIC ACTIVITY

The introduction of large retail stores to Devils Lake will expand its trade area for the short term. Based on past studies of Wal-mart stores, standard percentages have been produced that reveal the impact of a Wal-mart store on a prospective community. Wal-mart and K-Mart are service industries and they will not create other jobs in the service sector. The trade area will continue to decline in population and the increase in Devils Lake's overall retail sales, created by Wal-mart and K-mart, will begin to diminish. Devils Lake must therefore grow to replace this loss since it can not come from the trade area.

After examining the population cohort figures, the problem that faces the city is obvious. Figure 4 demonstrates how the population of the surrounding trade area of Devils Lake is retreating and will soon match the city itself. Figure 6, the projection of Devils Lake's population cohorts, reveals the 65 and over cohort as containing the largest number of people by the year 2010. Figure 7 illustrates the decline in population in every cohort for the surrounding trade area.

CONCLUSION

Considering the changes taking place in population cohorts within the Devils Lake trade area, there are several factors city leaders should consider.

1. Become aggressive in economic development. Population growth within the 20-50 age group can come only from within through jobs.

2. Without industrial jobs the age composition of Devils Lake will change the retail mix of the city and more younger cohorts will spend more money in Grand Forks.

3. Value added industry will keep Devils Lake a vital, active city.

REFERENCES

1. North Dakota at a Glance, ND Census Data Center, NDSU, pg. 124
2. Population Estimates for Cities, North Dakota 1990-1994, North Dakota Census Data Center, NDSU, pg. 1

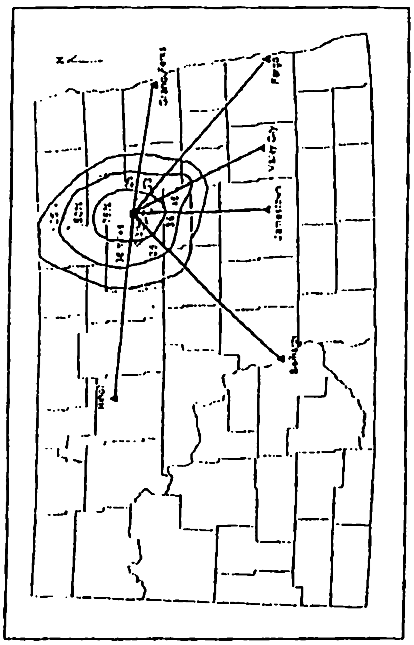


Figure 1. Devils Lake, North Dakota Trade Area.

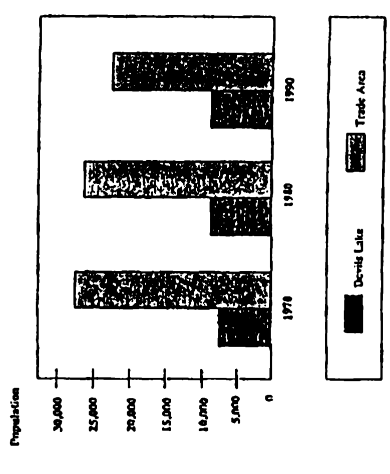


Figure 2. Population of Devils Lake and its Surrounding Trade Area.

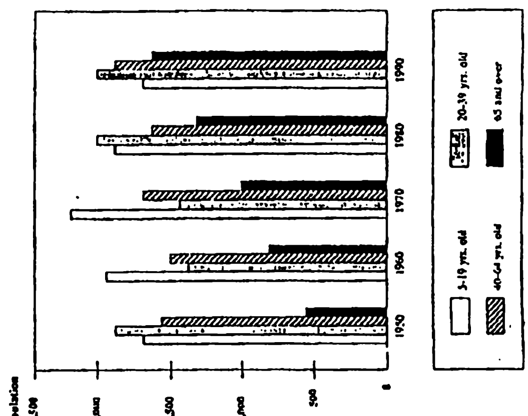


Figure 3. Devils Lake Population Cohorts.

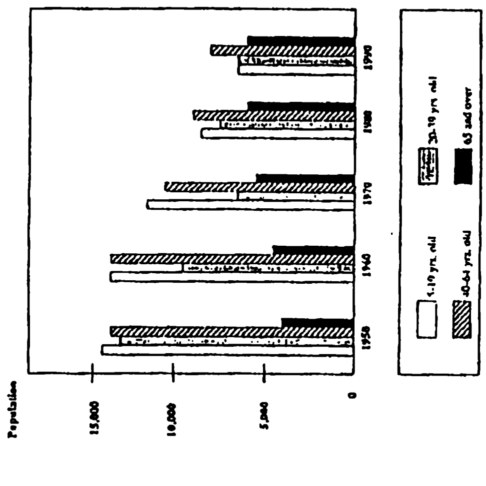


Figure 4. Population Cohorts of Devils Lake's Surrounding Trade Area.

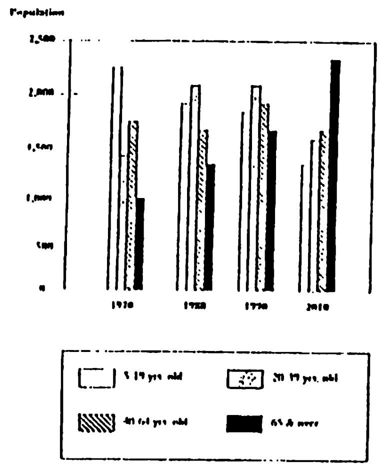


Figure 5. Population Projection of Devils Lake's Age Cohorts for the Year 2010.

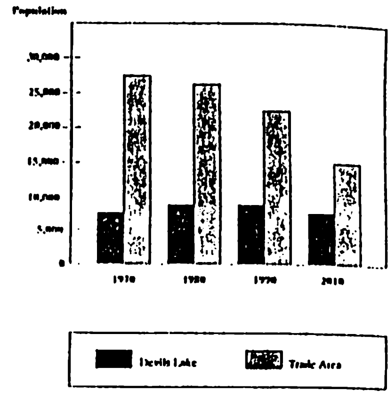


Figure 6. Population Projection of Devils Lake and its Trade Area for the Year 2010.

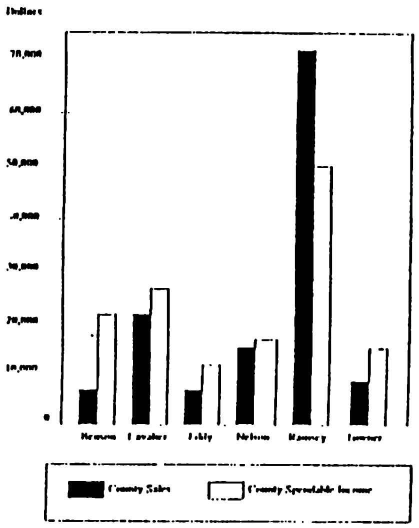


Figure 7. County Sales Versus County Spendable Income in the Devils Lake Trade Area.

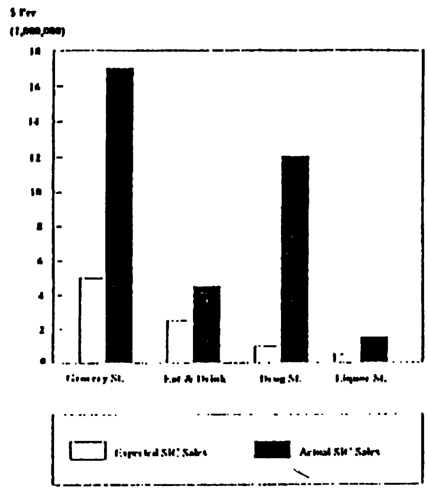


Figure 8. Devils Lake's Expected and Actual SIC Sales.

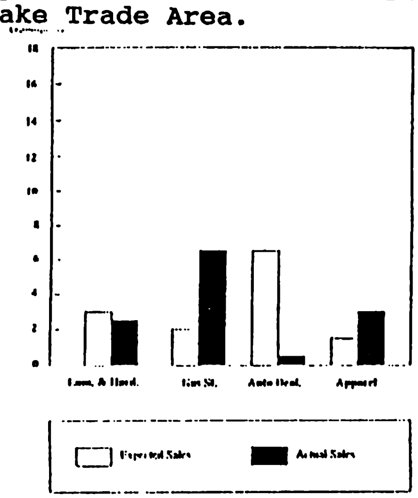


Figure 9. Devils Lake SIC Expected and Actual Sales.

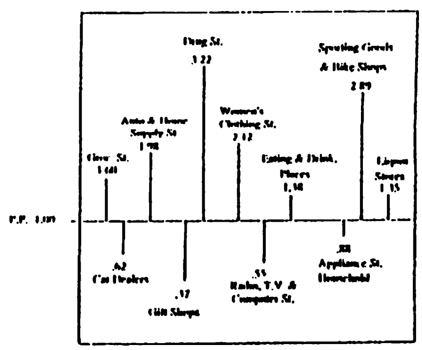


Figure 10. Devils Lake's SIC Pull Factors.

SYMPOSIUM: PROBLEMS AND PROSPECTS FOR COMMUNITY DEVELOPMENT IN NORTH DAKOTA

THE LANDSCAPE OF NORTH DAKOTA BEFORE MAJOR AMERICAN SETTLEMENT: PRELIMINARY OBSERVATIONS

John B. Anderton*
Department of Geography, University of North Dakota, P.O. Box 9020, Grand Forks, ND 58203

LEADERSHIP AND COMMUNITY DEVELOPMENT: THE CASE OF RURAL NORTH DAKOTA

Janet Kelly Moen*
Department of Sociology, University of North Dakota, Grand Forks, ND 58202

A PILOT STUDY OF FAST FOOD RESTAURANTS AS A FORM OF CULTURAL LANDSCAPE ELEMENT

Douglas C. Munski*
University of North Dakota, Grand Forks, ND 58202

AN APPLICATION OF GIS TO SPATIAL DETERMINANTS OF CRIME RATES IN FARGO

Mohammad Hemmasi* and Thomas Kessler
Department of Geography, University of North Dakota, Grand Forks, ND 58202

FORECASTS OF FUTURE STUDENT POPULATIONS IN NEW RESIDENTIAL DEVELOPMENTS IN THE GRAND FORKS PUBLIC SCHOOL DISTRICT

Dr. Floyd Hickok*
Grand Forks City Planning Department, Grand Forks, ND 58201

THE LANDSCAPE OF NORTH DAKOTA BEFORE MAJOR AMERICAN SETTLEMENT: PRELIMINARY OBSERVATIONS

John B. Anderton*
Department of Geography, University of North Dakota, P.O. Box 9020, Grand Forks, ND 58203
e-mail: anderton@badlands.nodak.edu

INTRODUCTION

When one looks at the plains and prairies of North Dakota today, one sees a landscape composed of fields, rangelands, farms, small towns, roads, and small cities. However, landscapes are made of various layers, composed of cultural and natural elements, created or influenced by the actions of people on the land (1). The present landscape of North Dakota merely represents the latest melange of cultural and ecological components, which form the uppermost layers that are currently most visible. This contemporary landscape was started when the region was first settled by pioneer homesteaders, farmers, and ranchers, primarily after about 1870. Cultural remnants of this pioneer, or frontier, landscape can be seen in the form of historic buildings, headstones in cemeteries, still-preserved wagon ruts, and other historic objects. However, beneath these historic layers are even deeper ones, which were formed prior to the time of major American settlement. Information on this older landscape is important to biogeographers, ecologists, and others who are trying to understand the evolution of northern Plains ecosystems, as well as to land managers interested in restoring some areas to natural vegetation, and to social scientists trying to understand the entirety of the region's landscape.

Landscape Interpretations

Although geographers and historians alike have focused much effort on the Western frontier and historic American settlement, few researchers have tackled questions concerning the landscape before major American settlement. What were these layers like? In other words, what was this place we now call North Dakota like before major American settlement? Ecologists indicate that the region now known as North Dakota was originally grasslands vegetation, varying from tall-grass prairie in the east to short-grass in the western part of the state (2). In most cases, the original prairie grassland, considered to be the "natural" vegetation of the region, has been attributed to climatic origins, as well as the impact of grazing herbivores (3, 4). The traditional interpretation of pre-American landscapes has been that the North American prairies were a grass-covered wilderness of sorts; a landscape that was largely untouched by human impact. However, Native American people were present in the pre-American landscape. Nevertheless, as Pyne (5) has observed, it is often assumed by the general public that the American Indian was incapable of greatly modifying his environment and that he would not have been much interested in doing so if he did have the capabilities. Denevan (6) has dubbed this questionable perception of the pre-Columbian Americas as a wilderness largely uninfluenced by humans, the "Pristine Myth." However, the ecological influence of Native Americans in the development of the prairie, especially in its eastern portion, has been recognized by some workers (3 ,4 , 7). Indeed, Anderson (3) maintains that most ecologists now believe that for the last 5000 years prairie vegetation in the eastern United States would have mostly disappeared if it had not been for the nearly annual burning of the grasslands by the North American Indians. Despite this statement, however, most ecological literature concerning the ecology of the North American Prairies is largely silent on the extent of the ecological influence of Native people.

Purpose of Study

The purpose of this study is to provide at least a preliminary reconstruction of the landscape of North Dakota prior to major American settlement (c. 1870). Using Denevan's (6) premise that Native peoples may have influenced and, in some cases, determined the "natural" flora and fauna of major regions, it was hypothesized that evidence would be found to indicate a Native American influence on plants, animals, and other resources on the pre-American landscape of what is now known as North Dakota.

METHODS

A number of possible sources of information may be used to get some sense of the landscape prior to major Euro-American settlement. These include remnants of pre-settlement vegetation, original surveyor's notes and maps, written accounts from explorers and travelers through the region, and proxy indicators such as fossil pollen, plant macro-fossils, faunal evidence, soils, and other indicators of environmental conditions. The primary source of information used in this study consisted of a number of first-hand observations taken from older journals, which were written prior to pioneer American settlement (Table 1). These journals were read to find descriptions of the landscape that might illuminate past environmental conditions.

Table 1. First-Hand Accounts of the Landscape of North Dakota Prior to Major American Settlement

Journal Author and Background:	Dates:	Present-Day Observed Area in and/or near North Dakota:
Pierre Gaultier de La Verendrye (8) - explorer, fur trader	1730-1739	Assiniboine River, Missouri River, central North Dakota
David Thompson (9)- geographer, explorer, fur trader	1797-1798	Souris River to Missouri River, central North Dakota, Red River Valley
Alexander Henry, the Younger (10) - fur trader	1800-1804	Red River Valley from Pembina to Park River, eastern North Dakota/ western Minnesota/ southern Manitoba
Major Stephen H. Long (11) - military expedition leader	1823	Red River Valley from Lake Traverse to Winnipeg, eastern North Dakota/ southern Manitoba
James E. Calhoun - member of 1823 Long Expedition (11)	1823	Red River Valley from Lake Traverse to Winnipeg, eastern North Dakota/ southern Manitoba
George Catlin (12) - painter, writer	1832	Missouri River, central North Dakota
Joseph Nicollet (13) - scientist, expedition leader	1838, 1839	Southwestern Minnesota, eastern North Dakota

RESULTS/DISCUSSION

Obviously, native people had an impact on their landscape. However, the extent of this impact is difficult to measure. On the northern plains, including North Dakota, native people had two basic cultural adaptations: semi-nomadic bison hunting and semi- sedentary village agriculture and hunting (14). In general, population numbers were probably relatively low. What types of ecological impact would be expected from such life ways, which could be readily observed and recorded by historic journal authors? What would be visible in terms of landscape components such as vegetation patterns and other obvious biological elements such as large herds of animals? Three basic types of ecological impact seem obvious: direct impact of settlement (immediate resource use), impact on animal populations due to hunting, and use of fire.

Of the three possibilities mentioned above, the third item was probably the most important element in the overall creation of the landscape. A recent collection of papers on the role of fire in North American tall grass prairies (15) indicates that fire was a necessary component in the maintenance of the eastern portion of the Great Plains. Ethnographic studies indicate that Native Americans burned the grasslands for a variety of different reasons, including driving of game (primarily buffalo) and for the improvement of grazing conditions for buffalo (16). Therefore, it was thought that evidence for widespread burning would be an obvious landscape element observed by the journal authors.

Fire in the Landscape of the pre-American North Dakota Plains

Fire-Maintained Open Landscapes

To begin, the indirect influence of fire is obvious in many journal entries which describe the openness of the prairies. In the earliest written observations of the region, Pierre Gaultier de Varennes de la Verendrye (8) in referring to the lands southwest of the Assiniboine River, remarks that "*...there is no wood in all that vast country* (p. 50)." In one of the most detailed journals from the period, Alexander Henry (10), a fur trader who spent the years 1800-1804 on the Red River, describes the area between present day Park River and Pembina as "*...one continual plain, where not the least hillock nor wood of any kind is to be seen* (p. 94)." He describes the area north of present day Grand Forks as "*...smooth and open, without a stick to be seen, except the woods of Red river, and some spots along the Turtle river* (p. 139)." While traveling between Devils Lake and the Red River in 1839, French explorer Joseph Nicollet (13) expressed concern over the availability of wood and water, noting "*the region is entirely without them* (p. 198)." Similar observations were also made farther west. After the steamboat he was passenger on became stuck on a sand bar in the Missouri River in 1832, the painter George Catlin (12) walked overland across part of what would become western North Dakota to reach a fur trading post. Catlin indicates, "*Every rod of our way was over continuous prairie, with a* *verdant green turf of wild grass of six to eight inches in height... (p.218).*"

The Canadian geographer and explorer David Thompson (9) suggests that the fire played a key role in maintaining the openness of the North American prairies. In his journal from wintering on the Red River in 1798, he notes "*Along the Great Plains, there are very many places where large groves of Aspins [sic] have been burnt, the charred stumps remaining; and no further production of Trees have taken place, the grass of the Plains covers them; and from this cause the Great Plains are constantly increasing in length and breadth...(p. 185-186).*" Thompson, who also traveled across what was to become the north-central part of the state in early winter of 1797 from the Souris River to the Mandan Indian villages along the Missouri River, also remarked on the presence of fire on the plains. Thompson (p. 167) describes the forests along the Souris River as very patchy, separated from each other by several miles. He goes on to say that in the summer , "*..when the grass is set on fire...*" only certain trees have a thick enough bark to avoid being killed. Thompson was probably talking about the fire-resistant bark of the Bur Oak. His descriptions also hint at a human source of ignition. On his return trip to the north, Thompson indicated that, "*The grass of these plains is so often on fire, by accident or design, and the bark of the Trees so often scorched that their growth is contracted, or they become dry...(p. 181).*"

Widespread Fire in the Landscape

The widespread presence of fire, as well as seasonality of occurrence is also clear from the journals. Thompson (9) indicates"*...and the whole of the great Plains are subject to these fires during the Summer and Autumn before the snow lies on the ground* (p. 181)." Alexander Henry's journal (10) from his trading post at Pembina, holds several entries that describe widespread prairie fires in the Red River valley during the spring and fall between 1801 and 1804. On April 30, 1802 he notes "*Fire on the plains in every direction* (p. 196)." For April 8, 1803, Henry indicates "*Plains on fire in every direction* (p. 210)." On October 4, 1803, he indicates "*Fire is raging at every point of the compass; thick clouds of smoke nearly deprive us of the sight of the sun, an at night the view from the top of my house is awful indeed. In every direction are flames...* (p. 228)." Later, on October 24 (1803), he notes "*The Plains are burned almost everywhere; only a few small spots have escaped the fury of the flames (p.229).*" In November of 1804, he notes the aftermath of a prairie fire as, "*Plains burned in every direction...,*" and he goes on to describe several buffalo wandering about the plains west of Pembina that were blinded by the same fire (p. 254).

Fire and Vegetation Patterns

The pattern of original forest growth along water courses in the region also seems to support the notion of fire being a major part of the landscape. Major Stephen H. Long (11), who directed a military expedition along the Red River in 1823, observed "*The woodlands of this country are mere fringes along the water-courses...* (p.179)" Alexander Henry (10) also describes the distribution of forests along the river. Writing about an area just north of the present-day international border, he indicates that "*the land on the E. side is well wooded for a mile in depth; then succeed low poplars and willows for two miles or more, where the plains commence* (p. 78-79)." It appears that because the rivers acted as fire breaks, stopping fires that would have most commonly been blown by prevailing westerly winds, the east sides of the rivers had more extensive groves of trees. David Thompson's (9) observations of the west side of the Red River in 1798 just north of the border also seem to support this conclusion, also. He notes (p. 185), "*We journeyed on the west side of the River; the whole distance was meadow land, and no other Woods than saplings of Oak, Ash, and Alder. From the many charred stumps of Pines it was evident this side of the River was once a Pine Forest.*" Joseph Nicollet (13), who explored what was to become southwestern Minnesota in 1838, also indicates that although rare, small groups of trees, called by his métis guides, "*l'ile de bois*" or islands of forest, could be found on the prairies, "*...which are protected from fires by streams of water or other irregularities of the terrain* (p. 56)."

Native Americans as a Source of the Fires

Were Native Americans responsible for the prairie fires recorded in the journals? Although lightning was undoubtedly a source of fires, it is clear that many prairie fires had their origins with Native people. Henry's (10) journal describes a prairie fire that was accidentally set by Cree Indians on December 1, 1801 on the south side of the Park River, where he "*...could plainly distinguish the flames, which at intervals rose to an extraordinary height, as they passed through low spots of long grass or reeds* (p. 158-159)." It appears that most fires were probably caused by people based on the seasonality of the occurrences. The historic journals indicate fires during the spring, fall, and winter, rather than during the summer months, when lightning frequency would be its highest during summer thunderstorms. But why burn the prairie? James Calhoun (11), a member of the 1823 Long Expedition to the Red River, in a rather lengthy discourse remarked that, "*Annual fires remove all vegetable deposit. The Indian sets fire to the prairie....*"and "*...we may safely say that all the prairies of the* *continent, with little exception, are burnt every year. Places that have had respite of only a few months are covered with dense thickets. Observation & reflection, so far has [as] I have capacity in viewing a subject interesting to me, have convinced me that fire is the cause of the existence of prairies* (p. 303)."

Evidence for the burning of vegetation as a traditional Native American land management practice are widespread for North America (6). On the Plains, Native people used fire for a variety of different reasons. According to Nicolet (13), who traveled through southwestern Minnesota and eastern North Dakota in 1838 and 1839 ( ), "*...all the prairies watered by the Mississippi and the Missouri are the work of the Indians who destroy by fire the rich vegetation to assure themselves of animal food* (p. 66-67)." Calhoun's first hand account from 1823 in the Red River Valley (11), indicates that Native Americans set fires to "*...distract pursuit by the smoke & by destroying all trace of his passage; to keep the country open & thus invite the buffalo, and enable him to see & chace [sic] his game; to give notice to his friends of his approach or to warn them of the presence of the enemy; the traders by the same mean[s] bring to them the Indians; the prairies are often burnt by the spreading of the fires of encampments...* (p. 303)."

Although the burning of prairies grasses could be used a warfare method, widespread firing of grasses was probably done for other reasons. In his exhaustive study of the natural history of the American bison, McHugh (16) indicates that "grass firing" was used as a means of encircling and driving bison herds on the eastern prairies (p. 69). Perhaps more importantly, McHugh (16) indicates that grass firing was also done by several plains tribes in the fall, winter, and spring to stimulate a premature crop of fresh green grass that would lure herds to the area (p.70). Recent studies have found that ungulates, such as bison, preferentially graze grass vegetation in burned areas because of the greater productivity and nutritive quality of forage following fire (4). Therefore, it is suggested that widespread burning of the eastern portion of the Great Plains was done by Native Americans to increase grass quality for grazing bison and maintain the openness of the region.

CONCLUSIONS

A Cultural Landscape before American Settlement

Today, prairie fires are a thing of the past and the modern landscape of North Dakota may be said to be in a fire suppression regime. The effects of fire suppression may be seen in areas, such as river valleys where forest growth is very dense. Had there been no human-induced fires on the part of Native Americans, much of North Dakota, especially the eastern portions, probably would have been more wooded, rather than open prairie, at the time of American settlement. Although the potential influence by Native American people on the ecology of the plains was small compared to that of modern society, the influence was of great duration. Archaeologists indicate that people have been living on the plains, including North Dakota, for at least 10,000 to 12,000 years (14). Such a long presence in the region allowed traditional Native American forms of land use, such as the practice of burning, to have a substantial impact on the landscape of North Dakota. Patterns of vegetation, reconstructed using historic journals, suggest that long-term Native American use of the northern Plains created a subtle cultural landscape rather than a "natural" landscape. The pre-American landscape of North Dakota was a fire ecosystem, maintained by Native Americans.

Future Research

The preliminary observations presented above are merely interpretations of historic journal records. The idea of prairie fires being largely attributed to human ignition is very debatable. Further evidence is needed before this notion can be firmly accepted or rejected. Future research should concentrate on further perusals of other historic journals for the region. Data concerning electrical storms should also be examined to determine the extent of fires caused by lightning. Sources of physical evidence, such as fire-scarred old growth trees, if they exist, may also lend proof to the human ignition thesis. Finally other forms of proxy data may exist in the region, including charcoal lens in pond deposits, or other stratigraphic records of widespread fires.

References

1. Norton, W. (1989) *Explorations in the Understanding of Landscape[,] A Cultural Geography.* Contributions in Sociology No. 77, Greenwood Press, New York.

2. Vankat, J. L. (1977) *The Natural Vegetation of North America.* Wiley and Sons, New York.

3. Anderson, R. C. (1990) The Historic Role of Fire in the North American Grassland. In *Fire in North American Tall grass Prairies* edited by Collins, S.L. and L.L. Wallace (p. 8-18). University of Oklahoma Press, Norman and London.

4. Risser, P. G. (1990) Landscape Processes and the Vegetation of the North American Grassland. In *Fire in North American Tall grass Prairies* edited by Collins, S.L. and L.L. Wallace (p. 133-146). University of Oklahoma Press, Norman and London.

5. Pyne, S. J. (1982) *Fire in America[,] A Cultural History of Wildland and Rural Fire.* Princeton University Press, New Jersey.

6. Denevan, W. M. (1992) The Pristine Myth: The Landscape of North America in 1492. *Annals of the Association of American Geographers* 82 (3): 369-385.

7. Stewart, Omer C. (1956). Fire as the First Great Force Employed by Man. In *Man's Role in Changing the Face of the Earth* (p. 115-133), edited by W. L. Thomas. University of Chicago Press, Chicago.

8. Burpee, L. J., editor (1927) *Journals and Letters of Pierre Gaultier de Varennes De La Verendrye and his sons.* The Champlain Society Publication XVI, Toronto.

9. Glover, R. (1962) *David Thompson's Narrative 1784-1812.* Publications of the Champlain Society, Toronto. Robert MacLehose and Company Limited at the University Press, Glasgow.

10. Coues, Elliot, editor (1897) *New Light on ...., The Manuscript journals of Alexander Henry (the Younger), fur trader of the Northwest Co. And David Thompson 1799-1814.* Published by Francis P. Harper, New York.

11. Kane, L.M., J.D. Holmquist, and C. Gilman, editors (1978) *The Northern Expeditions of Stephen H. Long, The Journals of 1817 and 1823 and Related Documents.* Minnesota Historical Society.

12. Catlin, George (1973). *Letters and Notes on the Manners, Customs, and Conditions of the North American Indians written during eight years' travel (1832-1839).* Dover Publications, New York

13. Bray, E. C. And M. C. Bray (1993) *Joseph N. Nicollet on the Plains and Prairies.* Minnesota Historical Society, St. Paul.

14. Schneider, Mary Jane (1994) *North Dakota Indians[,] An Introduction.* Kendall/Hunt Publishing , Dubuque.

15. Collins, S.L. and L.L. Wallace, editors (1990). *Fire in North American Tall grass Prairies.* University of Oklahoma Press, Norman and London.

16. McHugh, Tom (1972). *The Time of the Buffalo.* University of Nebraska Press, Lincoln and London.

LEADERSHIP AND COMMUNITY DEVELOPMENT: THE CASE OF RURAL NORTH DAKOTA

Janet Kelly Moen*
Department of Sociology, University of North Dakota, Grand Forks, ND 58202

Historically, leaders have served as the benchmarks of history. Much, if not most, of our documented legacy centers either on the actions or the thoughts of bold individuals who left copious deeds or documents for posterity to ponder, admire, emulate, celebrate, and in some few cases, to regret. Almost inevitably, these individuals were men, and in most cases their failings as leaders were minimized, ignored or forgotten. Thus the texts used to educate our youth are filled by an endless parade of larger-than-life leaders, marching across the pages, socializing generations to an image of leadership which few could hope to emulate.

With the rise of social science investigation, new understandings and conceptualizations of leadership began to take shape. Over the past century, such investigations into leadership as a distinct topic have evolved in phases. Logically following from historical tradition, early theories concentrated on traits of leaders, and were quite oriented toward individuals. Around the time of World War II, behavioral theories became established and flourished for a couple of decades. The 1960's saw the emergence of contingency theories, followed by an emphasis on transformational leadership, ethical leadership, and charismatic leadership. Most recently, Yukl (1) has attempted a holistic integration of insights from this voluminous body of theory and research.

Leadership theory has most often been linked to psychological paradigms, and in more recent years, the bulk of the literature has emanated from the fields of industrial psychology and organizational behavior. Hence the nature of much of the work centered around psychological and social psychological variables. In the more recent work, particularly that of Burns (2), followership has been elevated to a more significant place in the schema, and the significance of the activity of mobilization of others has been highlighted.

Meanwhile, the political and social context of the "maturing" of American society has left many in our country floundering in search for meaning, direction, or at least a semblance of value-consensus to focus civic activity on positive and constructive goals. Near brutal public scrutiny of elected officials, corporate executives, and other contemporary leaders has left the public apathetic and jaundiced, if not totally demoralized concerning the capacity of our leadership. Whether or not these popular figures are any worse than many of those who became legends of history is difficult to determine, but the effect is one of pervasive malaise. This malaise is poignantly underscored by the empirical fact that half of the eligible citizens in the world's leading democracy cannot inconvenience themselves to stop by a local polling both and cast their vote for their ultimate leader—the President of the United States.

Simultaneous with this rather pessimistic political and cultural scenario, a social movement of sorts has been brewing. It encompass a series of activities which have taken place across the county to promote the idea of "citizen leadership." It is comprised of some unlikely players, who may not be allied in fact, but are undoubtedly linked in spirit. The first, and probably oldest, segment of activities in the leadership development movement has been sponsored by local Chambers of Commerce in an effort to increase the pool of "knowledgeable" people in a given community who might be tapped for leadership roles. These programs typically attracted up to a hundred participants a year in a community building "course" which meet monthly from fall to spring, acquainting the group with various segments and issues of the community, and in some cases, offering them skill development in activities designed to help them to exercise their leadership potential. Enough of these programs developed across the country that, about two decades ago, their supporters saw their common purpose, and organized themselves as the National Association of Community Leadership Organizations. This organization has since grown to include over 400 member organizations, representing tens of thousands of participants, and identifies itself as COMMUNITY LEADERSHIP, or the National Association for Community Leadership. It is essentially an urban-oriented phenomenon, as participants must come from communities large enough to have an active Chamber of Commerce.

A second source of this leadership development effort was developed by the Cooperative Extension Service. Many counties across the country have had the luxury of maintaining an Extension leadership specialist. These people are trained in leadership development aimed at enhancing community development, and often more particularly, economic development. They have also formed a formal organization, the Association of Leadership Educators, which has about 150 members around the country. They work with people in predominantly rural areas, at the small town, county , regional, and occasionally state levels (3).

These types of activities have become so prolific that a National Clearinghouse for Leadership Programs has been established at the University of Maryland to help interested parties filter through the barrage of materials which have been created spontaneously across the country. The production of leadership development manuals, videos, and seminars has become a virtual cottage industry of modern society. The "shops" are strewn across college campuses, foundations, Extension offices and in private consulting firms.

The important message in these various leadership activities is that a transition is being made from a view of leadership as an elite activity to an endeavor in which many citizens may take part. It is a kind of democratization of leadership. Leadership is no longer viewed as a scarce commodity to be analyzed and studied but as a phenomenon which can be expanded as a skill to be taught in a community context.

North Dakota has four metropolitan communities in which the Chamber of Commerce sponsors these types of leadership programs: Grand Forks, Fargo, Bismarck, and Minot. In Grand Forks, for example, Leadership '85 began in 1985 and has continued with about 30 participants annually, forming a pool of about 350 individuals who have been challenged to engage in leadership activity. Three smaller communities, Williston, Jamestown and Grafton, have recently initiated successful programs. Telephone interviews were conducted with Chamber staff around the state in early 1997 and the resulting demographics of these programs are listed below in Table 1.

The collective efforts of each of these communities has provided a potential pool of over 1800 people who have demonstrated incentive to act in some type of leadership capacity. These numbers do not include the youth programs. For example, Fargo is sponsoring it's second year of a program for 36 sophomores and juniors from local public and private high schools. In Minot, the Community Leadership Institute routinely included two high school and two university students in their program for a few years.

Two factors in these types of community efforts which can enhance the potential of these leadership programs are the formation of "alumni associations," and community projects. The alumni groups provide an ever expanding network of participants who take an active interest in maintaining and continuing to develop and utilize their leadership skills and abilities. Three of the programs listed above have active alumni groups. Also, when programs ask the participants to do a community or field project, the energy of the group is mobilized to community service, and individuals have an opportunity to practice the skills which they are learning and discussing. At least three of these communities require a community project. Overall, the potential of this on-going effort scattered across the state might be greatly enhanced through the development of a state-wide network of leadership development programs. The Bismarck Chamber of Commerce has made some initial attempts to do this, and those involved agree that it is an idea whose time has come, but scheduling difficulties have limited any results to date.

In the rural areas, leadership has been left more to chance. The largest coordinated effort to date has been the Dakota LEADers program, which involved about 100 individuals in 16 communities across the state, over the period from 1989-91 (4). Other efforts, especially by Extension, and including the popular Family Community Leadership program, have often targeted high school students and youth organizations. Overall, people in rural communities have traditionally had less sustained access to capacity building activities than have their more urban counterparts. Most recently, the North Dakota Rural Development Council has made leadership development a priority item, and their efforts may further develop the potential of this creative tool.

Table 1
North Dakota's Chamber Sponsored Community Leadership Development Programs

Community	*Number of years operating*	*Approximate class size*	*Approximate total number of participants*
Bismarck	8	15	120
Fargo	14	36*	500
Grafton	3	12-15	40
Grand Forks	12	30	360
Jamestown	4	15	60
Minot	26	25-30	700
Williston	2	9-10	20
		TOTAL	**1800**

*recently expanded to 45

The major issue facing the North Dakota effort is the type of model, or absence thereof, of any attempt to enhance development in the state through the education and training of individuals being nurtured to take on leadership roles. The programs listed above operate on a fairly established model, although variety exists from program to program. In the smallest rural communities, however, the model for any kind of leadership development may be more nebulous. The brief review of theory and conceptualizations cited above should leave any astute reader wondering about the transferability of individualistic and corporate models of leadership for community development, especially in a particularly rural state. In fact, this is most problematic. What criteria should be advanced for a leadership development effort for any generally rural region, and for North Dakota in particular?

The logic of this task impels us to examine the terms "community" and "leadership" in a social context that takes into account the reality of geographically detached places. Four ideas form the corners of a relevant model. First, leadership must be viewed as a social, as distinct from an individual function. That is, by conceptualizing the leader as an actor in a social context, rather than as a social actor, the importance of social exchange is underscored. This orientation suggests that we look at the network of interactions in which any potential leader is embedded as a viaduct for bringing various kinds of resources from the larger society into a rural community. It also suggests that leadership can be conceptualized as a location in a social and geographic nexus.

Second, for the geographic morphology of rural communities, it may be convenient to divide those social networks engaged in by leaders as those which are local and those which are trans-local. In this model, trans-local networks may be seen as sources of many exchanges which could be made through appropriate contacts. These could be in the form of other contacts, ideas, programs and curriculums, grants, exchanges, or capital, for example. Comprehensive local networks, or those within the community itself, may be seen as mechanisms of equitable distribution of resources, as mobilization sources, or as support groups. The operative term here is on comprehensive community building, where all sectors are recognized and included, as opposed to "old boy" types of linkages.

Third, we can look at these two sets of social networks in a very comprehensive manner, to maximize the potential interplay of any leadership actor. People have different strengths in the way in which they interact with different community segments, and the members of those segments. The local community may be divided up into basic sectors, over which there may be some to very little overlap. Typically, communities have certain sectors which are heavily involved in development types of activities, and other sectors which have tremendous resources, but do not get involved in community or economic development. For example, education and religious sectors are often left out of development, while associations of growers or other economic actors join with political officials to spearhead community development efforts. On the trans-local level, an individual may interact with a trade organization, or professional association, but rarely are these trans-local contacts seen as resource suppliers for the larger local community.

Finally, if we think about ways of increasing the comprehensiveness of the individual network systems, a team, or collaborative model may work best for smaller rural communities. In this way, a community can take advantage of the sum of the linkages which a cohort of strategically selected citizens possess. This should actually guarantee that the whole become greater than the sum of the parts, through the synergistic interplay of the ideas, contacts, and resource exchange potential of members of the community.

This type of collaborative model is not entirely dissimilar to the cooperative growers facilities which are springing up across the state. Another indicator of the popularity of collaborative work in rural areas can be found in the community development corporations. It would seem that North Dakotans are particularly adept at working together in egalitarian organizational units. Thus this type of leadership model may indeed prosper in the more rural areas. It also holds the potential to give confidence and security to individuals who are new to the "leadership field, " for example women or younger people.

Properly organized, smaller rural communities can capture development potential similar to that of the larger cities in the state where North Dakotans have proven their capacity to create and sustain leadership development programs. The next step is to coordinate existing efforts and create viable new initiatives to serve smaller communities. The potential exists for the use of the Interactive Video Network (IVN) to greatly increase the educational program delivery component of such an effort. What is then needed is a sponsor, preferably at the state level, to organize a structure to link all of the leadership activities into a strategic force authorized to capture the latent energy of the citizens of the state. This effort begins with the realization that leadership is *everybody's* business.

References

1. Yukl, G. (1994) Leadership in Organizations, 3rd edition. Prentice Hall, New York.

2. Burns, J.M. (1978) Leadership. Harper & Row, New York.

3. Association of Leadership Educators (1996) Leadership in A Changing World: Proceedings of the Annual Conference. Burlington, VT.

4. Moen, J. (1995) Integrating Theory and Practice: Leadership and Community Development in the Dakotas. *Journal of the Community Development Society* 26 (1):93-109.

A PILOT STUDY OF FAST FOOD RESTAURANTS AS A FORM OF CULTURAL LANDSCAPE ELEMENT

Douglas C. Munski*
University of North Dakota
Grand Forks, ND 58202

Introduction

Contemporary American textbooks for introductory human geography courses are marked by a high degree of similarity in terms of identifying the topics deemed to reflect important themes and concepts in this social science-oriented form of geographic inquiry (1, 2, 3, 4, 5). Chapters which generally are presented to the first-year undergraduate--who typically has not had a formal course in geography since the seventh grade--include an overview to core concepts of the discipline, population, migration, language, religion, ethnicity, folk culture, popular culture, economic sectors with a focus upon primary sector and secondary sector activities, rural settlement, urban settlement, political systems, and human-environment interaction, i.e., the human response to natural hazards and resouce management. Tucked within the representative chapter that emphasizes popular culture frequently are case studies concerning phenomenon which are supposedly of keen interest to undergraduates, e.gs., the diffusion of sports, music, transportation forms, and foodways. It is this last cultural trait, foodways as expressed in the distribution of fast food restaurants, that has been frequently utilized for study in the introductory human geography course at the University of North Dakota using the community of Grand Forks as a living laboratory. Preliminary results garnered through 15 years of student writing exercises and more than 19 years of personal anecdotal experience with this phenomenon indicate that fast food restaurants are landscape elements that might be overlooked frequently as components in the cultural landscape of this North Dakota city.

Literature Review

Studies of the cultural landscape which emphasize popular culture phenomenon have been a major research focus since the late 1960s of those geographers best identified as interpreters of the vernacular landscape (6, 7). Such geographical inquiries frequently are undertaken as qualitative studies with a humanistic approach and are more akin to the works of anthropologists and historians (8). While some attention is given to quantitative techniques for analysis in many of these popular culture studies, even those papers emphasize the goal of the research is to explain the sense of place associated with that phenomenon and given geographical locations.

Among the most significant geographical studies on foodways is the work of Richard Pilsbury (9). His seminal monograph, From Boarding House to Bistro, is a major starting point for the analysis of the distribution of any type of restaurant as an element of the cultural landscape. Taking a historical geography approach, Pilsbury succinctly covers the shift of American eating habits outside the home from pre-Federalist Era taverns to modern national franchised eating emporiums such as the "Big Three" of hamburger sales fame: McDonald's, Burger King, and Hardee's. Yet, geographical treatises on foodways such as that of Pilsbury and articles from other geographers (10, 11) need to be supplemented with literature drawn from restaurant trade publications and the popular press, too.

The food industry in the United States is a highly complex and increasingly vertically integrated economic activity. The contracting of certain primary sector producers, e.g., potato growers, to insure consistency of raw material for selected secondary sector manufacturers, e.g., french fry processors, so that the food retailers in the tertiary sector, e.g., McDonald's, will have a standard product has been influenced heavily by market research at the quaternary sector level which in turn has been driven by administrative decisions in the quinary sector as illustrated by John F. Love in McDonald's: Behind the Arches (12). Thus, restaurant trade publications reflect a shift from describing the latest cooking gadget to increased attention to the global market place seeing as how American popular foodways have been diffused internationally well before the first McDonald's outside the United States was established in Canada in 1967 (13). It must still be remembered, however, that the American-style fast food restaurant increasingly is making its presence felt on the international scene as pointed out by Butler (14) concerning Burger King's plans to supplant the salmon-rice burger in Japan with its brand of beef-based burger. Meanwhile, back in the United States there is a growing acceptance of foodways from other parts of the world such that even fast food restaurants are offering a version of Italian cappacino as an alternative to coffee and soda pop as is seen in the three Hardee's facilities in Grand Forks. Yet, how do fast food restaurants have impact upon the cultural landscape as a form of landscape element?

Methodology

In order to answer the above question, a research methodology needed to be developed and implemented. Based upon a search of the literature of popular culture as reflected in the writings of historians, anthropologists, and culture studies specialists as well as geographers, the decision was made to approach this problem-statement more in terms of qualitative research (8). This also reflects the orientation of the introductory human geography course at the University of North Dakota that takes into account the predominantly non-quantitative backgrounds of undergraduates enrolled in that course seeing as how the results of this research are intended to be a prototype for future research by that group of students.

Having elected to follow a qualitative research design, the next step was to clarify the definition of the phenomenon to be studied and to determine the time frame and locational geographical limits of such a study. While there are numerous ways of defining a fast food restaurant, certain key elements emerge: a limited menu and specific combinations of what is to be found on that menu, reliance upon pre-packaged and frozen food products, absence of waiter/waitress service, ordering off a menu board at a food counter, speedy preparation of food, relatively inexpensive food, availability of a drive-thru as a means of food delivery, food servers/preparers in a standardized uniform if a franchised fast food establishments, and the restaurant itself having a distinctive style of interior design as well as standardized exterior if part of a local, regional, national, or internationl chain of fast food establishments. Pizzarias, full menu cafeterias, dairy bars, fruit juice bars, donut shops, taverns, and steakhouse-style cafeterias, e.g., Ponderosa, were excluded from consideration in this pilot study. These characteristics became the basis for the working definition of a fast food restaurant.

The time frame for this study was limited to 1996 and restricted solely to the city limits of Grand Forks, North Dakota and East Grand Forks, Minnesota. These limitations were made for reasons. First, the goal of the study was not to be a comprehensive historical geography of eateries in metropolitan Grand Forks. Rather, this research was to be a pilot study to establish benchmark data. Second, while Grand Forks Air Force Base (15 miles west of Grand Forks) is part of metropolitan Grand Forks, access to this military installation for field work could not be arranged satisfactorily. Finally, the parameters of the experimental design needed to be relatively simple for later use with the undergraduates in the introductory human geography course at the University of North Dakota.

Data Collection

Using the aforesaid definition of a fast food restaurant, an inventory was made of the restaurants of Grand Forks using various telephone directories, city directories, and publications from the local convention and visitors bureau. Thirty-two restaurants qualified as fast food restaurants using the restricted definition with the majority of them being affiliated with a major international fast food restaurant chain. Verification of the location of these fast food restaurants was made by visiting each one and field notes as well as photographic records made of the exteriors of these facilities; taking photographs of interiors was discouraged by the various managers because of local interpretations concerning company policies against unauthorized or unofficial documentation of conditions within the specific fast food restaurant.

Data Analysis

Once the data was collected, the locations of the fast food restaurants were plotted on a map of Grand Forks similar to what is being used in the introductory human geography course at the University of North Dakota for student projects using the local community as a living laboratory (Figure 1). The distribution of the 32 fast food restaurants were analyzed in terms of density per thousand people, dispersion over the study area, and pattern types (random, clustered, and linear). While this form of data analysis is highly simplistic, it is an effective means to establish benchmark conditions for future study of the phenomenon using more more sophisticated qualitative measures and quantitative technques of analysis.

Interpretation of Results

Preliminary results of this research have indicated that certain fast food restaurants which are international chains definitely dominate the cultural landscape of the this form of eateries in Grand Forks. Six major points have emerged in this study thus far. First, the high level of popularity of sandwich shops is seen in the great number of Subway facilities and in the seemingly near even dispersion of this fast food restaurant at eight sites in the study area. Subway's local management cleverly has joined with selected business to provide itself a built-in market at three of those sites in addition to the chain's free-standing stores. Having a Subway in a truck stop that also includes a traditional trucker's restaurant as in the case of the Big Sioux Truck Stop on 32nd Avenue South just off of Interstate 29 may seem at first to be a contradiction, but the relationship is mutually beneficial as two different clientele's can be serviced while stopping to purchase gas and related travel necessities. The Subway facility in the Holiday Station Store on 32nd Avenue South, while seemingly close to the one in the Big Sioux Truck Stop, is drawing the east-west traffic in contrast to the former's orientation to the north-south traveling public. The east-west traffic along U.S. Highway 2 is lured in for a sandwich by Subway through its shared facility with the Holiday Station Store along that route in East Grand Forks. Subway, however, apparently has not eliminated the local grinder/hero sandwich type restaurants as exemplified by Fat Albert's and the Red Pepper's two facilities.

Second, Grand Forks is a hamburger town when it comes to the competition to Subway. There is no fast food restaurant that emphasizes fish as would be the case of Long John Silvers or Skipper's nor is there any fast food restaurant which emphasizes hot dogs such as Skinner's which is located in Selkirk and Winnipeg, Manitoba. There is only one chicken-oriented fast food restaurant, KFC, and one roast beef-style eatery, Arby's. None of the West Coast Japanese-style fast food restaurants such as Yoshida Bowl had reached Grand Forks by the end of 1996, leaving the ethnic fast food market in the kitchens of Mexican-style eateries such as the solitary Taco Bell and three Taco John's. If a person is hungry for a hamburger, however, one can have a Big Mac attack at three locations with McDonald's, "have it your way" at one of three Burger King facilities, or "hurry on down for a charchoal-broiled" burger at three sites selling Hardee's products. Despite the pressure from the "Big Three" of hamburgerdom (McDonald's, Burger King, and Hardee's), local hamburger-oriented fast food restaurants survive in the form of Burger Time and two seasonal drive-ins: the Kegs in Grand Forks and the Riverside Drive-in of East Grand Forks.

Third, the distribution of the fast food places is predominantly linear. If one were to make a series of looping rides along Washington Street, Columbia Road, 32nd Avenue South, or Gateway Drive (Business U.S. Highway 2), one could reach almost all the fast food restaurants in Grand Forks and East Grand Forks. These, of course, are the most heavily traveled highways, and because of zoning restrictions, the often expected campus eateries are not found on the periphery of the University of North Dakota; however, there is a fast food restaurant (a Burger King) and a second one planned to open (Subway) within the campus as contracted eateries which reflects the nationwide trend toward dining contracts between fast food restaurants and institutions of higher education.

Fourth, the cultural landscape is not cluttered with fast food restaurants along the highways and streets even though such facilities do dominate their respective sites with their distinctive architectural styles, especially at night with various forms of electric lighting. Unlike many communities of a similar population size, Grand Forks does not really have a "fast food alley" with each of the competiting chains in direct line of sight, i.e., "cheek and jowl," with each other and clustered on key intersections. Thus, as a landscape element, fast food restaurants are present but are not overwhelming the cultural landscape of Grand Forks.

Fifth, the central business district (CBD) of both Grand Forks and East Grand Forks are devoid of eateries that clearly met the limited definition of a fast food restaurant for this pilot study. Admittedly, several establishments came close to being included in the data base because of meeting several of the criteria of the definition. However, the slowness of the service at those eateries became the key factor in excluding them as being a fast food restaurant.

Finally, the fast food restaurants of Grand Forks are frequently overlooked as a component of the cultural landscape because of how ubiquitous they are and are so often a destination for meals and snacks by the residents of Grand Forks. Because of the standardized architectural styles of the regional, national, and internationl chains of fast food restaurants, the travelers and local community members do not have a visually surprising streetscape to search when seeking a place to eat. Only one of the fast food restaurants of Grand Forks, the Kegs, maintains its distinctive 1950s style theme architecture (two enormous root beer barrel kegs joined by a boxy small kitchen structure with drive-in curb service). The nostalgia for such a drive-in is reflected in the construction of the Riverside Drive-in during the early 1990s along one of the classic 1950s designs for such a restaurant. For the fast food restaurant affaciando, it is disappointing to discover that both the Kegs and the Riverside Drive-In are only seasonal in operation, too. Thus, the cultural landscape of Grand Forks with respect to fast food restaurants may be described as being bland.

Conclusion

This preliminary study has emphasized a qualititative approach to the study of fast food restaurants as an element of the cultural landscape of Grand Forks, North Dakota. Furthermore, it has triggered more questions than answers for the researcher, so there definitely is a need for a more indepth study of this phenomenon. First, there is a need for a detailed historical geography of the eateries of Grand Forks in general and of fast food restaurants in particular. Based upon anecdotal evidence, it appears that the shift of eateries from the central business district to major thoroughfares and malls is a process that has been going on in Grand Forks from the late 1940s and that local drive-ins have declined in favor of fast food restaurants affiliated with regional, national, and international chains from the mid-1960s. Second, there is a need for a quantitative study of the location of the current distribution of the fast food restaurants. Nearest neighbor analysis or a similar quantitative technique might be useful to begin to explain theoretically why those structures are placed where they are with other studies to include interviews with owners and managers as well as city planners to explain the actual locational decision-making process. Third, there is a need for a combined qualitative and quantitative study to assess people's perceptions of the role that fast food restaurants play as an element of the cultural landscape. A short questionnaire should be administered to an appropriate sample of residents and non-residents drawn from all parts of the community of Greater Grand Forks as a key part of this proposed future research. Finally, there is a need to transfer this research into a usable form to be taken by undergraduates in the introductory human geography course as a starting point for their own geographical inquiries in studying popular culture. Studying the topic of fast food restaurants as an element of the cultural landscape should be a springboard for examining other phenomenon, e.g., the distribution of movie theaters, sports facililties, and other retail-oriented facilities. Such research, which is of importance to marketing and land use planning, would help undergraduates to recognize that even a phenomenon in popular culture as ubiquitous as a fast food restaurant has significant and complex geographical implications when it comes to the changes that have, are, and will be taking place in the cultural landscape not only of the United States but elsewhere in the globalization of popular culture.

Bibliography

1. Fellmann, J., Getis, A., and Getis, J., 1996. Human Geography: Landscapes of Human Activities. Fourth Edition. Dubuque, IA: Brown & Benchmark.

2. deBlij, H. J., 1996. Human Geography: Culture, Society, and Space. Fifth Edition. New York: John Wiley & Sons, Inc.

3. Bergman, E. F., 1995. Human Geography: Cultures, Connections, & Landscapes. Englewood Cliffs, NJ: Prentice-Hall.

4. Jordan, T. G. and Roundtree, L., 1990. The Human Mosaic: A Thematic Introduction to Cultural Geography. New York: Harper & Row.

5. Stoddard, R. H., Wishart, D. J., and Blouet, B., 1989. Human Geography: People, Places, and Cultures. Englewood Cliffs, NJ: Prentice-Hall

6. Gaile, G. L. and Willmott, C. J., 1989. Geography in America. Columbus, OH: Merrill Publishing.

7. Agnew, J., Livingstone, D. N., and Rogers, A. 1996. Human Geography: An Essential Anthology. Cambridge, MA: Blackwell Publishers

8. Eyles, John and Smith, David M., eds. 1988. Quantitative Methods in Human Geography. Totowa, NJ: Barnes & Noble Books.

9. Pillsbury, R., 1990. From Boarding House to Bistro: The American Restaurant Then and Now. Boston: Unwin Hyman.

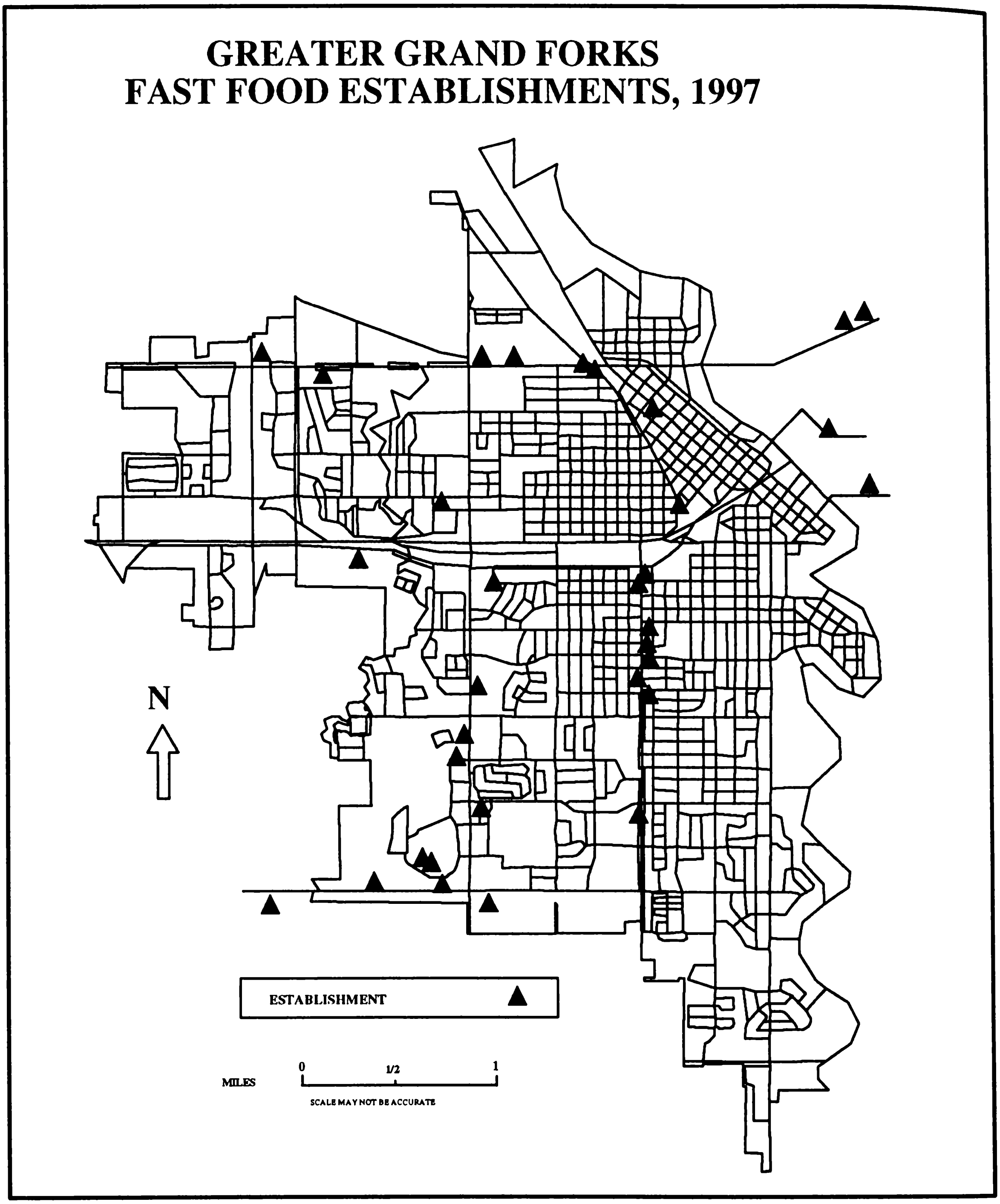
10. Jakle, J. A., 1995. "Roadside Restaurants and Place-Product-Packaging" in Fast Food,Stock Cars, & Rock-n-Roll (ed. by G. O. Carney). Lanham, MD: Rowman & Littlefield. Pp. 97-117.

11. Carstensen, L. W., 1995. "The Burger Kingdom: Growth and Diffusion of McDonald's Restaurants in the United States, 1955-1978" in Fast Food, Stock Cars, & Rock-n-Roll (ed. by G. O. Carney). Lanham, MD: Rowman & Littlefield. Pp. 119-128.

12. Love, J. F., 1986. McDonald's Behind the Arches. New York: Bantam Books.

13. Tennyson, J. 1993. Hamburger Heaven. New York: Hyperion.

14. Butler, S., 1997. "The Whopper killed the salmon burger," U.S. News and World Report 122: 2 (January 20, 1997), p. 57.


GREATER GRAND FORKS
FAST FOOD ESTABLISHMENTS, 1997
N
ESTABLISHMENT
MILES
0
1/2
1
SCALE MAY NOT BE ACCURATE

AN APPLICATION OF GIS TO SPATIAL DETERMINANTS OF CRIME RATES IN FARGO

Mohammad Hemmasi* and Thomas Kessler
Department of Geography, University of North Dakota, Grand Forks, ND 58202

Introduction

Personal safety is a primary concern when selecting a neighborhood of residence. Today, one of the strongest and most publicized issues influencing urban land and housing values is personal safety (1). Declining property values and high turnover in ownership often characterize neighborhoods with high crime rates and residents living in fear. Past research has found the central business districts (CBD) and outlying commercial areas are focal points for illegal activity in many urban areas, although social stressors such as racial issues, socioeconomic status, and overcrowding are the predictors of illegal behaviors (2,3,4). In the past three decades many studies have examined the role of various attributes on relative land and housing values in urban settings (5,6). The current research uses a geographic information system (GIS) to analyze existing and potential neighborhoods at risk for decline in Fargo, North Dakota (7).

Currently Cass County, the home of Fargo, has a population of approximately 110,000 residents. The sprawling metropolitan area of Fargo-Moorhead is world renowned in agricultural research and agribusiness, besides being a regional transportation hub and provider of educational, financial, retail, and medical services to the surrounding communities. Fargo dominates the state of North Dakota not only in population size, but in most development indicators. In some industrial classifications (SIC), such as finance, insurance, real estate, and construction, Cass County has more than one-third of the state's workers.

The physical makeup of Fargo differs as much within the city as it differs from its surroundings rural communities. The residents perceive the city as two distinct regions: North Fargo and South Fargo. North Fargo contains much of the older residential areas, downtown businesses, and the North Dakota State University (NDSU). South Fargo consists of newer houses, many apartment buildings, and most of retail businesses and restaurants. Most of the owner-occupied housing lies along the river and on the northern and southern ends of the city. The downtown area, along the I- 29 and I-94 is dominated by apartments with intermittent houses, duplexes and condominiums. West Fargo consists mostly of owner-occupied housing. Affluent families purchase housing on the outlying areas and along the river.

Although Fargo is less culturally diverse than many American cities, several minority groups reside in the city. In 1990, minorities made up only about 3.3 % of Fargo's residents. Hispanics and Native Americans comprise the largest percentage of Fargo's non-Caucasian population. The largest percentage of minorities live in North Fargo, mainly downtown and in the central city. A much smaller percentage of the minority population lives in central South Fargo or West Fargo, a relatively new residential city. Most of the minorities are of lower financial status and must live in the older, less maintained part of the city. By contrast, the newer apartment complexes and single-family homes constructed in West Fargo and South Fargo have almost no minority residents.

Consistently in the top 50 metropolitan areas for low violent and property crime according to *Places Rated Almanac* (8), Fargo's crime rate has yet to become unmanageable. Although no American city is without its share of criminal activity, Fargo's uncommonly low crime rate helped it earn the distinction as *Money Magazine's* 14th most desirable place to live for 1996 (9). It is important to note that although occurrences of illegal activity were used as an indicator of neighborhood insecurity in this study, one should realize the small number of crime incidences in the study area. Fargo's average crime rate of about 40 per ten-thousand population in 1995-96 (Figure 1-a) is far lower than the national average of more than 500 per ten-thousand population during the recent years.

Data

We analyzed and compared data from twelve months of Cass County and Fargo court proceedings with ten socioeconomic variables at the census blockgroup level (Table 1). The *Fargo Forum* newspaper, which publishes crime data at approximately two week intervals, was used as the primary data source in this study. The data for one year was obtained from daily newspapers dated July 1995 through June 1996. Addresses of 422 non-traffic and non-alcohol related offenders were secured through content analysis of Fargo Municipal Court proceedings and Cass County District Court proceedings. The offenses were categorized as either (1) drug offenses, which includes either possession of a controlled substance or drug paraphernalia; (2) theft offenses, which include theft and shoplifting; (3) assault offenses, which includes assault, simple assault, stalking and related offenses; (4) mischief offenses, such as criminal mischief, disorderly conduct and related misdemeanors; (5) serious offenses, which includes felony assault, harassment, burglary, and violent crimes. Traffic-related crimes and alcohol offenses were not included due to the sheer number of infractions. Each offender then was assigned to his or her sixty-six corresponding U.S. Census Bureau blockgroups, or neighborhood geographic units. The socioeconomic

TABLE 1. MEAN, STANDARD DEVIATION (SD) AND COEFFICIENT OF VARIATION (CV) FOR THE ANALYZED VARIABLES

Variable	Description	Mean	SD	CV
Drug	Drug crime rate (offense / 10,000 population)	11.7	18.3	155.9
Theft	Theft crime rate (offense / 10,000 population)	19.1	22.5	117.1
Assault	Assault crime rate (offense / 10,000 population.)	9.8	20.6	211.1
Mischief	Mischief crime rate (offenses per 10,000 pop.)	14.3	29.0	202.2
Serious	Serious crime rate (offenses per 10,000 pop.)	0.9	3.3	379.3
Tcrime	Total crime rate (offenses per 10,000 pop.)	55.8	74.0	132.7
Minority	Minorities as a percentage of total residents	3.3	2.5	75.6
Income	Median Income	27,897	12,481	44.7
Housval	Median Value of the owner-occupied houses	65,586	27,140	41.4
Renter	Renters as % of total residents	47.0	28.3	60.1
Rent	Gross monthly rent	346.9	144.9	41.8
Poverty	Workers at or below the poverty level	16.7	16.1	65.7
Unempl	Unemployed persons as % of total workers	2.9	1.9	96.4

variables for the same blockgroups were extracted from the CD-ROM of 1990 Census of Population and Housing.

Table 1 contains the mean, standard deviation (SD), and coefficient of variation (CV) for crime and socioeconomic variables analyzed in this preliminary study. The coefficient of variation is useful for measuring and comparing the spatial relative variability in the data. Among the five broad categories of crimes, theft offenses occurred most frequently and were geographically widespread as shown by the coefficient of variation of 117.1. On the other hand, eight serious crimes were recorded during 1995-96 and only one blockgroup had two of these incidences (CV=379.3; Figure 1-b). In comparison, the other socioeconomic variables were more evenly distributed than crime rates. The unemployment rates (CV= 96.4) are the most unevenly distributed and the gross monthly rent variable (CV=40.8) is the least. Noting that Fargo's 2.9% unemployment rate is much lower than the national average of more than 5% is also important.

Next, it was necessary to produce ArcView layers or "shape" files, which could then be used to analyze spatial patterns and query, or examine the database (7). Environmental System Research Institute's (ESRI) Data Automation Kit claimed to be able to convert U.S. Census Bureau TIGER/Line files to usable ArcView coverages, but appeared to have many defects inherent to the software. Instead, it was possible to use Bondata's Dr. Dolittle Software to convert TIGER/Line files to Atlas.BNA format, then use the Data Automation Kit to convert the BNA file to useable ArcView coverages.

Analysis

Residents of Fargo-West Fargo committed 422 non-traffic and non-alcohol related offenses during the period July 1995 - June 1996. Approximately one-third of all offenses in Fargo were theft related (38%). Nearly an equal percentage of drug (21%) and mischief (23%) related offenses were committed. Assault and serious crime rates were the least recorded offenses during this period. When Fargo's total crime rate was mapped, the assumption of higher crime near primary and secondary nodes is validated. Figures 1-a and 1-f show a generalized surface representation of crime rates across Fargo-West Fargo. By far the highest offense rates are found in downtown Fargo, followed by West Fargo business district/ West Acres shopping area.. Secondary areas of high crime include: 13th Avenue South commercial strip, and South University commercial nodes.

Simple correlation analysis was performed on selected relevant variables (Table 2). Not surprisingly, the socioeconomic variables of median income and housing value both had significant negative correlations with each crime category and total crime rate. The most interesting result came with percentage of renters. Renters as a percentage of total residents correlated most highly of any variable with total crime rates, and quite strongly with each individual offense category, although gross monthly rent failed to reach significance with any crime variable. Percent minorities failed to reach significance with every category except theft, which correlated positively. Poverty rates, another indicator of socioeconomic status, also correlated positively and significantly. Population per square mile, along with percentage of males and females, failed to correlate significantly with any crime category, nor did unemployment rates.

Although the above significant correlation coefficients revealed the presence of an overall covariation between crime rates and its predictor variables, it did not produce information on the spatial patterns and processes of crime within the city. Applying ArcView GIS to the databases can best achieve this objective. After loading the shape files for Fargo and "joining" the database of variables, it was a simple task of using ArcView's query tool to enter the variables and mathematical operators necessary to generate the desired spatial output. The first query requested was a map of neighborhoods with the highest total crime rates. The query was entered as [Tcrime > 90.0], which yielded the ten blockgroups with highest crime rates (Figure 1-c). Next a query was performed for each of the four most highly correlated variables: median income, median housing value, percent renters, and percent below the poverty level. For comparison, the ten blockgroups with the highest crime rates are shown in a darker outline.

Next, the blockgroups in the lowest 25th percentile for median income were selected. The generated map shows the result of the query for [Income < 20,000], or neighborhoods with a median income of less than a $20,000/year. Seven of the ten neighborhoods of highest crime are also shown to have a median income of less than $20,000. Another map (not included in this paper because of space limitation) shows the result of the query for blockgroups in the lowest 25th percentile for housing value, or [Housval < 50,000]. Six of the ten top crime neighborhoods also have a median housing value of less than $50,000. The fourth query, [Renter > 65.5], illustrated the neighborhoods with greater than 65.5% renters, or the top 25th percentile for total renters. Seven of the top ten crime neighborhoods fell into this category. The final query, [Poverty > .22], requests blockgroups with greater than 22% of the workers at or below the poverty level, or in the top 25th percentile for poverty status. This query yielded five of the ten top crime neighborhoods.

ArcView's capability of multiple queries was used to produce maps with other combinations of the four predictor variables included. For example, one map revealed the result of a query for the two variables which correlated most highly with total crime, median income, and percent renters. The query ([Income <20,000] and [Renter>65.5]), or blockgroups having a median income of less than a $20,000/year in addition to percentage of renters greater than 65.5, yielded six of the top ten top crime neighborhoods. A final query was performed requesting blockgroups which meet the criteria of all previous queries (Figure 1-d). Two of the seven blockgroups that meet the criteria for ([Income] and [Renter>65.5] and [Housval<50000] and [Poverty>22]), are also top crime neighborhoods.

Simple Correlation Coefficients were calculated for the five socioeconomic variables in Table 2. All variables except the percentage of renters and unemployment were highly intercorrelated. The assumption that these variables are "independent" of one another would have been violated if a multiple regression technique was used. Thus, a simple method for developing a composite index of quality of life was applied to these variables. Each blockgroup's values on Income, Housval, Renter, Poverty, and Unempl variables were scaled, so that the best score in each variable was made equal to 100, and the worst to zero. These calculations were accomplished with the formula:

$$S = (R - Rw / Rb-Rw) \times 100$$

where R is the raw score of each blockgroup's socioeconomic variable, Rw is the worst value, and Rb is the best value in all blockgroups for a given category. The scores for each of the blockgroups' socioeconomic variables were averaged to arrive at a composite score, or Quality of Life Index (QLI). A QLI of 100 would suggest the highest score on all variables, with a score of zero indicating lowest overall score. Figure 1-e shows a generalized spatial representation of the quality of life composite scores. Next linear regression equations were calculated for the six offense categories as a function of the quality of life composite index. The relationship between total crime rates and the composite index of quality of life is shown in the following equation.

$$Y = 122.55 - 1.38 X; \quad R \text{ square} = 0.298; \quad N=66$$

All the parameters are statistically significant at >0.01 level. Finally, the residuals from the above regression equation were analyzed to identify outlier blockgroups and to fine tune the model.

Discussion

With the high correlations between crime and the variables of income, housing, and poverty status, crime is apparently related to general economic well-being within the city of Fargo (2, 4). All the neighborhoods identified as highest in total crime rates are in areas of cheaper housing, often multistory apartment complexes. This type of housing is attractive to the lower income individuals and families who neither can afford more expensive housing, nor afford to drive great distances to their place of employment.

TABLE 2. SIMPLE CORRELATION COEFFICIENTS BETWEEN CRIME AND SOCIOECONOMIC VARIABLES AT THE BLOCKGROUP LEVEL

Variable	Income	Unempl	Poverty	Housval	Renter	Minority	Crime
Income	1.000	-.295*	-.588***	.748***	-.827***	-.511***	-.416***
Unempl		1.000	.351**	-.315**	.084	.253*	.117
Poverty			1.000	-.450***	.484***	.553***	.364**
Housval				1.000	-.446***	-.361**	-.313**
Renter					1.000	.448***	.509***
Minority						1.000	.232
Crime							1.000

*Significant at .05 level; **Significant at .01 level; ***Significant at .001 level.

It is interesting that neither of the two West Fargo blockgroups identified in the top ten for total crime rates matchedany of the four socioeconomic queries. A possible explanation for this finding may be due to the growth of outlying areas during the period 1990-1996. Since the most current population totals available came from the 1990 Census, and crime data is from 1995-96, areas of high population growth are likely to be underrepresented. Thus one must be careful when interpreting the blockgroups of southern West Fargo, and the far North and South of Fargo, which have seen extensive housing booms in the last few years. Also interesting is the under representation of crime in the blockgroups surrounding the North Dakota State University campus, in the upper central region of Fargo. Since most college students reside in these neighborhoods, the percentage of renters is high, median income is relatively low, and poverty status is high, which would be expected to relate to higher crime totals. Instead, total crime is low.

This study failed to shed light on the minority-crime debate (10). Although theft rates correlated highly with areas of high racial diversity, the small population of minorities in Fargo and West Fargo lend little credibility to the assumption that areas of greater racial diversity are more crime stricken. Two other variables that failed to reach significance were population per square mile (index of crowding) and unemployment rates. Although previous studies on crime in large metropolitan areas have shown these two variables to be related to crime, a smaller urban area such as Fargo has least problems with crowding or unemployment.

The practical application of GIS in tracking crime and socioeconomic status within a metropolitan area is extensive (11, 12, 13, 14). Neighborhood development is an area where GIS can certainly play a significant role. Federal organizations such as the Department of Housing and Urban Development (HUD) provide millions of dollars through its Community Development Block Grant (CDBG) program to the cities each year. The CDBG helps municipalities and other government units develop viable urban communities by funding projects that provide decent housing; produce a suitable living environment; and expand economic opportunities, principally for low - and moderate - income persons residing in a CDBG target area (15). GIS can help identify neighborhoods in need of intervention. Figure 1-f clearly shows that the need for neighborhood development in North-central and Downtown Fargo is ever present.

Although Fargo's crime rate is far from epidemic proportions, reports of increased violent crime and gang activity have led to increased public interest in personal safety. By continuously updating a database, police departments can utilize a GIS to track the spread and growth of crime in the city. Crime preventive organizations can rely on the system's capabilities to assign crime watchers and to maximize "human development" resources.

Conclusion

For three decades GIS has been utilized successfully to tackle a wide range of problems, but only recently has this technology been applied to the geography of illegal behavior (11, 13, 14). The current research has examined the role of socioeconomic factors in predicting criminal behavior, and how GIS can be used to illustrate and analyze these patterns. Variables such as median income, percentage renters, poverty status, and housing value are the best predictors of crime in Fargo. Although the socioeconomic variables analyzed in this study helped predict crime in some respects, even when eliminating the extreme outlier, the variables in this study only explained about 30% of the total crime in

Fargo. The utility of GIS for spatial pattern analysis, including crime patterns, is limited by the reliability and validity of the utilized database. Implications for future research include expanding the variable pool to include spatial variables (location, accessibility), amenities (recreation, community centers), temporal variables (seasonal variability), and especially matched data.

ArcView is an effective tool for illustrating spatial crime patterns and the socioeconomic variables which determine these patterns. With a limited database, this research used ArcView to display areas at risk of decline, which would require city government to target them for neighborhood development, area funding, and neighborhood crime watch programs. In the long-run, elimination of general poverty through "human development" strategies, provision of decent housing, and urban renewal programs will help to further reduce crime rates in the city.

References

1. Glazer, N. (1987). The South Bronx story: An extreme case of neighborhood decline. Policy Studies Journal, 16(2), 269-276.

2. Hsieh, C. C. and Pugh, M. D. (1993). Poverty, income inequality and violent crime: A meta-analysis of recent aggregate data studies. Criminal Justice Review, 18(2), 182-202.

3. Taylor, R. B. (1995). The impact of crime on communities. Annals of the American Academy of Political and Social Science, 539, 28-45.

4. Harries, K. (1995). The ecology of homicide and assault: Baltimore City and County, 1989-91. Studies on Crime and Crime Prevention, 4(1), 44-60.

5. Cadwallader, M. (1996) Urban Geography: An Analytical Approach, Prentice Hall: Upper Saddle River, NJ.

6. Hemmasi, M. And D. A. Hansen. (1993). "A Comparative Analysis of Housing Values in Large North Dakota cities," Bulletin: ANDG, Grand Forks, pp. 1-17.

7. Hutchinson, S. and Daniel, L. (1995). Inside ArcView. Santa Fe, NM: Onward Press.

8. Boyer, R. and Savagea, D. (1993). Places Rated Almanac: Your Guide to Finding the Best Places to Live in North America. Chicago: Rand McNally and Company.

9. Money News Media (1996). http://pathfinder.com/@@E6dyigYAU1BEW6*T/money/Best-cities-96/monlist.htm.

10. Petrunik, M., and Manyon, J. R. (1991). Race, socioeconomic conditions, and crime in Canadian cities: An exploratory study. Paper presented to the Society for the Study of Social Problems.

11. Betts, M. (1993). Computer maps help cops catch crooks: Desktop mapping. Computer World, 27(7), 32.

12. Geake, E. (1993). How PCS predict where crime will strike. New Scientist, 140(1896), 17.

13. Miller, T. (1993). GIS helps San Bernardino police take a byte out of crime. American City and County, 108(3), 42-43.

14. Witkin, Gordon. (1997). Making Mean Streets Nice: Computer Maps that Take the 'Random' Out of Violence, U.S. News & World Reports, December 30, 1996/January 6, 1997, 63.

15. Huxhold, W. E. and Martin, M. (1996). GIS guides city's neighborhood funding efforts. GIS World, 9(6), 54-56.

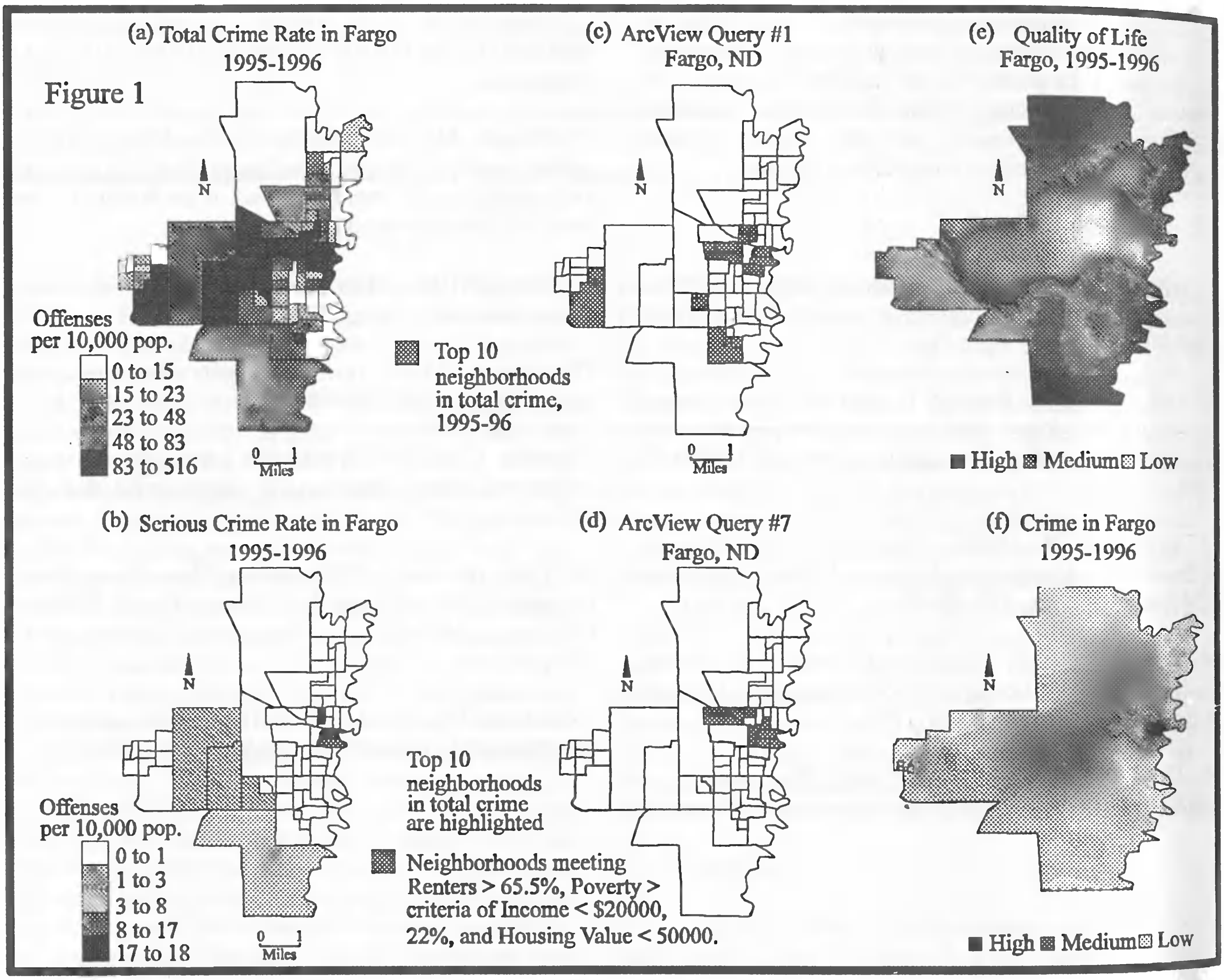


Figure 1
(a) Total Crime Rate in Fargo 1995-1996
N
Offenses per 10,000 pop.
0 to 15
15 to 23
23 to 48
48 to 83
83 to 516
0 1 Miles
(c) ArcView Query #1 Fargo, ND
N
Top 10 neighborhoods in total crime, 1995-96
0 1 Miles
(e) Quality of Life Fargo, 1995-1996
N
High Medium Low
(b) Serious Crime Rate in Fargo 1995-1996
N
Offenses per 10,000 pop.
0 to 1
1 to 3
3 to 8
8 to 17
17 to 18
0 1 Miles
(d) ArcView Query #7 Fargo, ND
N
Top 10 neighborhoods in total crime are highlighted
Neighborhoods meeting Renters > 65.5%, Poverty > criteria of Income < $20000, 22%, and Housing Value < 50000.
(f) Crime in Fargo 1995-1996
N
High Medium Low

FORECASTS OF FUTURE STUDENT POPULATIONS IN NEW RESIDENTIAL DEVELOPMENTS IN THE GRAND FORKS PUBLIC SCHOOL DISTRICT

Dr. Floyd Hickok*
Grand Forks City Planning Department, Grand Forks ND 58201

GIS development requires a great deal of time and expense. Critics often question its value. Some of this criticism is justified because too little effort is placed on finding practical applications for utilizing GIS and its many attribute files. The following is an example of one such application.

Planning for future schools requires the best possible estimates of future school age population in developing areas. The basic methodology used here involves merging data from the School District Enrollment file with information from the City's property file.

A file containing one record per student was obtained from the district office with the following data: student ID number, school, grade level, and home address. Table 1 is a cross-tabulation of that information. The district has nearly 10,000 students including those at the Grand Forks Air Force Base.

The Planning Department geo-coded each student record by adding a property numbers. This was done by matching home addresses with property addresses. This was by far the most tedious and time consuming part of the process. Home addresses were entered in such a variety of ways that most had to be matched manually. Once property numbers had been added to each student record, any information in the property file could automatically be added to that record. The two items of data critical to this study are land use and year of construction. The land use code in the property file distinguishes various types of residential uses as well as non-residential uses.

It seems reasonable to assume that the demographic characteristics of housing which will be built in the near future will be similar to that which was built in the recent past. The average number of students living in single family houses varies greatly depending on the year the house was built. See Table 2. Most houses built before 1970 average about 0.5 students per house. Those built in the 1970's average about 0.75. Houses built since 1980 average slightly more than one student per house. These numbers indicate the importance in considering the age of housing. In this study it is assumed that housing built in the near future will have the same characteristics as those built since 1980. Table 3 gives a breakdown of the number of students by housing type and grade level for housing built since 1980. It also gives the number of students per acre of these types of developments.

There is greater interest in K-6 since there will be one or more new elementary schools built in the foreseeable future. Single family housing has by far the highest number of K-6 students per unit, over twice that for multiple family or mobile homes. Single family attached are largely townhouses occupied by older people. Students per acre is quite different from students per housing unit because of the great difference in housing densities. The overall number of students per acre of single family housing (3.08) is very little more than for mobile homes (2.92). Multiple family is not that far behind at 2.52. Mobile homes have more K-6 students per acre than single family.

In order to make use of this information for making forecasts for future development, it is necessary to estimate what portion of development will be devoted to each housing type. Table 4 shows the percentage of land area by residential type with new construction in 1980 to 1996. Over half was taken by single family (57.2). Assuming that future house development occurs at this ratio, then all of the elements necessary are available for making forecasts of number of students in developing areas.

All neighborhoods want to have an elementary school. One neighborhood in Grand Forks which does not have a school is the area west of Interstate 29, known as Richards West. This area has 195 acres designated in the 2015 Land Use Plan for future residential development. Table 5 applies the results of this study to that area. If that area were to develop as forecast, there would be 276 elementary students in the area. There are currently 248 K-6 students living in the area. Of these 103 attend Lake Agassi and 116 go to West Elementary. With those already there and the future forecast the area would have over 500 elementary students. Whether this is enough to justify a new school is a decision for the school board.

Table 6 and the accompanying map show areas of future residential development and forecast student populations. This methodology works well for forecasting student populations in totally developed areas. It must be greatly modified for forecasting for areas in various stages of development. In these areas the number of single family vacant lots is often already known and plans have been approved for new apartments to be constructed in the near future. In these areas, one must go through the database property by property to assess the potential for new housing construction.

The practical uses for GIS and related databases is only limited by the imagination and ingenuity of its users.

Table 1.

School	K	1	2	3	4	5	6	7	8	9	10	11	12	Other	Total
	Grade Level														
BFK	65	72	59	60	64	51	73							6	450
BLT	42	35	48	37	34	42	38							0	276
CBE	122	115	116	107	110	101								22	693
CHS										425	338	311	275	0	1,349
CNT	76	82	93	91	77	84	105							28	636
COM										11	45	28	33	0	117
JNK	75	90	89	89	100	100	86							1	630
LAZ	96	63	71	68	55	55	63							7	478
LCK	39	49	42	49	52	42	52							2	327
LIN	19	31	27	28	28	29	24							0	186
NTE	83	80	80	69	67	67								0	446
NTM							157	130	127					0	414
RRH										397	352	342	295	0	1,386
SDR								210	232					0	442
SOH								224	234					1	459
VKG	54	58	57	43	45	41	48							5	351
VLY								200	188					6	394
WLD	38	29	20	23	24	25	38							1	198
WNP	33	36	33	29	41	38	41							0	251
WST	42	55	46	43	59	56	49							1	351
Total	784	795	781	736	756	731	774	764	781	833	735	681	603	80	9,834

Table 2
PUBLIC SCHOOL STUDENTS
LIVING IN SINGLE FAMILY HOUSES BY YEAR OF CONSTRUCTION

Year Built	Housing Units	Students	Students/Unit
Before 1930	2,158	1,155	0.535
1930 to 1939	428	220	0.514
1940 to 1949	736	277	0.376
1950 to 1959	1,647	825	0.501
1960 to 1969	1,326	720	0.543
1970 to 1979	1,235	944	0.746
1980 to 1989	571	601	1.053
1990 to 1996	432	469	1.086

Table 3
PUBLIC SCHOOL STUDENTS
PER HOUSING UNIT AND ACRE
BY HOUSING TYPE

	Single Family*	Single Family Attached*	Multiple Family*	Mobile Home
Housing Units	1,016	600	2,464	897
Students	1,080	70	323	437
K-6	559	26	200	262
7-8	188	14	45	64
9-12	331	30	73	106
Students per Unit	1.063	0.117	0.131	0.487
K-6	0.550	0.043	0.081	0.292
7-8	0.185	0.023	0.018	0.071
9-12	0.326	0.050	0.030	0.118
Units per Acre	2.9	9.0	19.2	6.0
Students per Acre	3.08	1.05	2.52	2.92
K-6	1.60	0.39	1.56	1.75
7-8	0.54	0.21	0.35	0.43
9-12	0.95	0.45	0.58	0.71

* Housing Units Built 1980 to 1996

Table 4
PERCENTAGE OF LAND AREA BY RESIDENTIAL TYPE
WITH NEW CONSTRUCTION, 1980-1996

Single Family	57.2
Single Family Attached	14.5
Multiple Family	21.6
Mobil Home	6.7

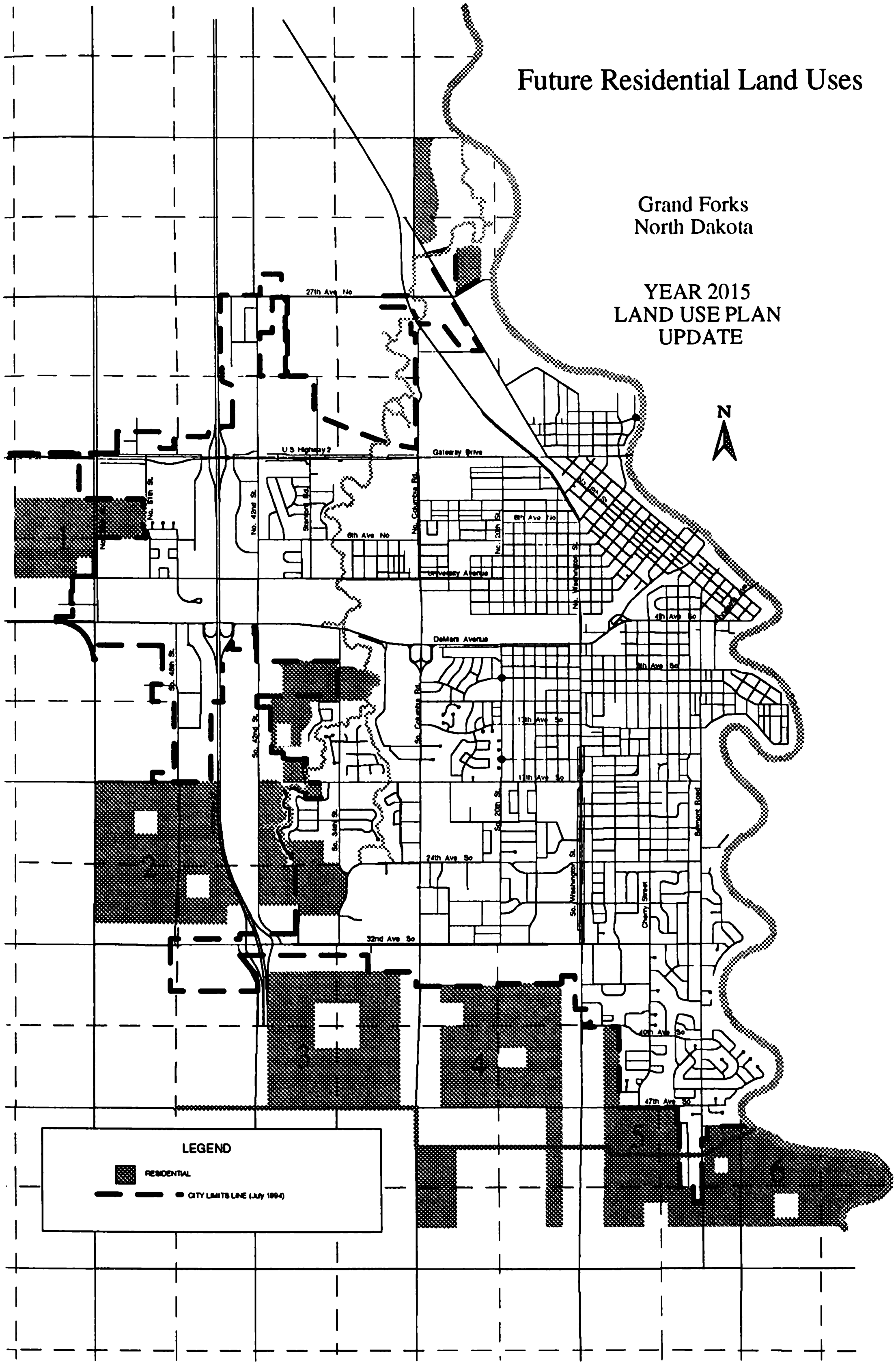
Table 5
FORECAST PUBLIC SCHOOL STUDENTS
IN PROPOSED UNDEVELOPED RESIDENTIAL AREAS
OF RICHARDS WEST AREA

	Single Family	Single Family Attached	Multiple Family	Mobile Home	Total
Percent Acres	57.2	14.5	21.6	6.7	
Acres	111	28	42	13	195
Units per Acre	2.9	9.0	19.2	6.0	
Expected Units	322	254	804	78	1,458
Expected Students	342	30	105	38	515
K-6	177	11	65	23	276
7-8	60	6	15	6	87
9-12	105	13	25	9	152

Table 6
FORECASTS OF FUTURE STUDENT POPULATIONS BY AREA

	Acres	All Students	K-6
Area 1	195	515	276
Area 2	404	1,067	570
Area 3	375	990	529
Area 4	446	1,177	629
Area 5	188	496	265
Area 6	395		

Refer to the map on the next page for the location of the numbered areas. In this table the total number of students is estimated to be 2.64 per acre and 1.41 K-6 students per acre. These rates do not seem to be valid for Area 6.



Source: GF/EGF MPO
Prepared by: Grand Forks - East Grand Forks Metropolitan Planning Organization (GF/EGF MPO)

SYMPOSIUM: APPLICATIONS OF STATISTICAL MODELING METHODS

NORTH DAKOTA — SMARTEST KIDS IN THE NATION? A LOOK AT THE SAT SCORES AS A MEANS OF RANKING STATES IN THE UNITED STATES

Jodi R. Rylance[1]* and M. B. Rao[2]
[1]PRACS Institute, Ltd., Fargo, North Dakota and [2]Department of Statistics, North Dakota State University, Fargo, North Dakota.

INTERVAL-CENSORED TYPE II PLAN: AVERAGE TIME TAKEN TO EXECUTE THE PLAN

Surekha Mudivarthy* and M. Bhaskara Rao,
Department of Statistics, North Dakota State University, P.O. Box 5575, Fargo, ND 58105

A STATISTICAL DATA ANALYSIS FOR IDENTIFYING IMPORTANT FACTORS FOR MAXIMUM PRODUCTION OF DURUM WHEAT HAPLOIDS

Surekha Mudivarthy and M. Bhaskara Rao*
Department of Statistics, North Dakota State University, Fargo, ND 58105

CARNIVORE SCENT-STATION SURVEYS: STATISTICAL CONSIDERATIONS

Glen A. Sargeant* and Douglas H. Johnson
Department of Wildlife Ecology, University of Wisconsin, 226 Russell Labs, 1630 Linden Drive, Madison, WI 53706 (GAS) and United States Geological Survey, Biological Resources Division, Northern Prairie Science Center, 8711 37th St. SE, Jamestown, ND (DHJ)

NORTH DAKOTA — SMARTEST KIDS IN THE NATION? A LOOK AT THE SAT SCORES AS A MEANS OF RANKING STATES IN THE UNITED STATES

Jodi R. Rylance[1]* and M. B. Rao[2]
[1]PRACS Institute, Ltd., Fargo, North Dakota and
[2]Department of Statistics, North Dakota State University, Fargo, North Dakota.

INTRODUCTION

North Dakota is #2 in the Nation in SAT Math Scores. This headline appeared in an article published by the Fargo Forum in 1994. A year later, North Dakota had moved into the number one spot. Are the graduating seniors in North Dakota the smartest in the nation? Looking only at the average SAT math scores, you might think so. A professor at Penn State University says, "NO". He claims that in general, the higher the percentage of students taking the SAT in a state, the lower the average SAT score for the state. The goal of this project is to estimate the true average score on the math portion of the SAT for each state, if all high school seniors had taken the test, and then rank the states based on the estimates.

The Scholastic Assessment Test or SAT is a standardized multiple choice exam used by many colleges and universities as part of the admissions process. There are two sections to the exam, math and verbal. Each section is scored separately. The scores range from 200 to 800 for each section. There is also a third section to the exam which is an experimental section and does not count towards the final score. This section is used by the Educational Testing Service or ETS to determine whether or not the exam is harder or easier than past exams. The SAT can be taken more than once for those students who would like to improve on their scores. It is worth noting that some colleges use a similar exam as part of their admissions process, the American College Testing program or ACT.

METHODS

The basic assumption we make is that only the academically best students take the SAT. Initially, we assumed that the SAT scores of all high school seniors in a state have a normal distribution with unknown mean μ and standard deviation σ, but we have only the top (p x 100) percent of scores, where p is the participation rate, i.e., the proportion of high school seniors who have taken the test. As a matter of fact, we do not have actual SAT scores of those who took the test. We have only the average SAT score, the standard deviation, and participation rate for each state (The College Board, [1]). If the scores of those who took the test are available, the validity of the distributional assumption can be tested. However, the assumption on the model enables us to estimate μ for each state. We used the method of moments to do the estimating.

To do the analysis using an exponential distribution, where the probability density function (pdf) is given by

$$f(x) = \frac{1}{\sigma} e^{-\frac{x-200}{\sigma}}, x \geq 200,$$

we assumed that the SAT scores in a state, if all high school seniors had taken the test, have the exponential distribution given above.

Finally, a regression line was fitted to the original SAT data by taking the response variable to be the state's average SAT score and independent variable to be the state's participation rate. This analysis is based on the methods used by Powell and Steelman (3), where the average SAT scores are regressed on the participation rates for each state. This method estimates the average score for each state and calculates the residual by subtracting the estimated average SAT score from the reported average SAT score. The state with the largest non-negative residual, as per the regression model, would be ranked number one.

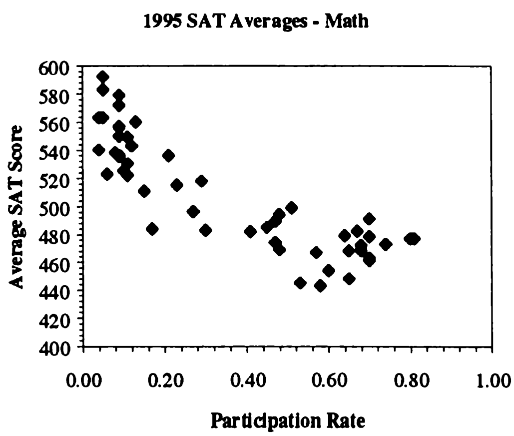
RESULTS

Table 1 shows the ranking of the states using the original data. Based on this table, North Dakota is ranked number one, and the midwest states dominate the top ten. A distinct trend is present in the original data — the lower the participation rate, the higher the average score. This trend is pictured in Figure 1.

Table 1. 1995 Average SAT Math Scores
Ranked by State

Rank	State	Average	stdev	p	Rank	State	Average	stdev	p
1	North Dakota	592	112	0.05	27	Washington	494	117	0.48
2	Iowa	583	114	0.05	28	New Hampshire	491	124	0.70
3	Minnesota	579	113	0.09	29	Alaska	489	120	0.47
4	Wisconsin	572	116	0.09	30	California	485	130	0.45
5	South Dakota	563	114	0.05	31	West Virginia	484	117	0.17
6	Utah	563	128	0.04	32	Nevada	483	120	0.30
7	Illinois	560	123	0.13	33	Hawaii	482	130	0.67
8	Kansas	557	118	0.09	34	National	482	127	0.41
9	Nebraska	556	119	0.09	35	Maryland	479	130	0.64
10	Missouri	550	124	0.09	36	New Jersey	478	128	0.70
11	Michigan	549	126	0.11	37	Connecticut	477	129	0.81
12	Tennessee	543	119	0.12	38	Massachusetts	477	131	0.80
13	Mississippi	540	122	0.04	39	Texas	474	121	0.47
14	Alabama	538	123	0.08	40	New York	473	127	0.74
15	Montana	536	116	0.21	41	Vermont	472	116	0.68
16	Oklahoma	536	121	0.09	42	Florida	469	122	0.48
17	Louisiana	535	121	0.09	43	Maine	469	116	0.68
18	New Mexico	530	124	0.11	44	Delaware	468	125	0.68
19	Wyoming	525	115	0.10	45	Virginia	468	124	0.65
20	Arkansas	523	121	0.06	46	Indiana	467	120	0.57
21	Kentucky	522	121	0.11	47	Rhode Island	463	123	0.70
22	Colorado	518	118	0.29	48	Pennsylvania	461	120	0.70
23	Ohio	515	122	0.23	49	North Carolina	454	117	0.60
24	Idaho	511	118	0.15	50	Georgia	448	118	0.65
25	Oregon	499	117	0.51	51	Washington DC	445	150	0.53
26	Arizona	496	118	0.27	52	South Carolina	443	113	0.58

Figure 1.



Under the assumption of normality, any state ranked 30 or below ended up with the estimated average score below 200 (Table 2). This is not possible, since the minimum score possible on the math portion of the SAT is 200. However, it is interesting to note that the results for the states with high participation rates seem quite reasonable. Connecticut is ranked first, followed by Massachusetts, New Hampshire, New York and New Jersey. All of the states in the top ten have participation rates of 67% or higher, and all of the states in the top twenty-five have participation rates above 40%. When ranking the states under the assumption of normality, you see that in general, the lower the participation rate, the lower the average score. Due to the problem of having so many values below the minimum score, it is obvious that this distribution is not suitable for our data.

Table 2. 1995 Average SAT Scores
Ranked by State — Normal Distribution

Rank	State	Average	p	Rank	State	Average	p
1	Connecticut	421.02	0.81	27	Montana	209.13	0.21
2	Massachusetts	416.87	0.80	28	Nevada	206.76	0.30
3	New Hampshire	403.10	0.70	29	Arizona	202.63	0.27
4	New York	396.07	0.74	30	Ohio	183.83	0.23
5	New Jersey	387.27	0.70	31	Illinois	119.53	0.13
6	Vermont	383.78	0.68	32	Idaho	114.38	0.15
7	Maine	380.78	0.68	33	Tennessee	111.84	0.12
8	Hawaii	379.51	0.67	34	West Virginia	78.91	0.17
9	Pennsylvania	375.94	0.70	35	North Dakota	68.53	0.05
10	Rhode Island	375.81	0.70	36	Minnesota	65.58	0.09
11	Delaware	372.93	0.68	37	Michigan	65.00	0.11
12	Maryland	365.57	0.64	38	Kentucky	57.20	0.11
13	Virginia	363.39	0.65	39	New Mexico	53.68	0.11
14	Georgia	348.45	0.65	40	Iowa	50.18	0.05
15	Oregon	347.62	0.51	41	Wisconsin	44.95	0.09
16	North Carolina	338.15	0.60	42	South Dakota	30.18	0.05
17	Indiana	335.54	0.57	43	Alabama	25.70	0.08
18	Washington	330.41	0.48	44	Kansas	20.86	0.09
19	South Carolina	324.10	0.58	45	Wyoming	17.24	0.10
20	Alaska	317.82	0.47	46	Nebraska	15.32	0.09
21	Texas	301.39	0.47	47	Missouri	-13.40	0.09
22	Florida	298.42	0.48	48	Oklahoma	-13.77	0.09
23	California	289.44	0.45	49	Louisiana	-14.77	0.09
24	National	269.23	0.41	50	Arkansas	-18.01	0.06
25	Washington, DC	261.70	0.53	51	Mississippi	-212.54	0.04
26	Colorado	240.00	0.29	52	Utah	-226.55	0.04

When looking at the exponential distribution, the results are easier to believe (Table 3). Once again, Connecticut is the leader, with an average score of 428.79 and a participation rate of 0.81. As with the normal distribution, the states with high participation rates, Massachusetts, New Hampshire, New York and New Jersey, round out the top five. The interesting changes lie in the states with the low participation rates. Using this distribution, North Dakota drops to number 46, with an average score of 298.10. This is approximately 51 points lower than the national average and approximately 131 points lower than Connecticut. You can see that under the assumption of an exponential distribution, the results are roughly opposite from the original data.

The results from fitting a regression line to the data seem more realistic than either distributional method, since we directly take into account the participation rate of each state, and using this participation rate, adjust the average SAT score. As with the original data, North Dakota is ranked number one out of all the states. North Dakota is followed by Minnesota, Iowa, Wisconsin and Connecticut (Table 4). When using the residual method of ranking the states, participation rate does not seem to have as much of a direct effect on the results. There is not a noticeable trend between the participation rates and the residuals. The top ten contains a mixture of states with high and low participation rates.

Table 3. 1995 Average SAT Scores
Ranked by State — Exponential Distribution

Rank	State	Average	p	Rank	State	Average	p
1	Connecticut	428.79	0.81	27	Montana	331.22	0.21
2	Massachusetts	426.47	0.80	28	Nevada	328.40	0.30
3	New Hampshire	414.50	0.70	29	Arizona	328.17	0.27
4	New York	409.82	0.74	30	Ohio	327.55	0.23
5	New Jersey	404.91	0.70	31	Illinois	318.41	0.13
6	Hawaii	401.36	0.67	32	Minnesota	311.21	0.09
7	Vermont	396.30	0.68	33	Tennessee	309.93	0.12
8	Maine	394.13	0.68	34	Wisconsin	309.16	0.09
9	Rhode Island	393.86	0.70	35	Michigan	308.81	0.11
10	Delaware	393.41	0.68	36	Idaho	307.35	0.15
11	Maryland	392.91	0.64	37	Kansas	304.75	0.09
12	Pennsylvania	392.38	0.70	38	Nebraska	304.46	0.09
13	Virginia	387.31	0.65	39	New Mexico	302.89	0.11
14	Oregon	378.68	0.51	40	Missouri	302.70	0.09
15	Georgia	373.33	0.65	41	West Virginia	302.45	0.17
16	Indiana	370.92	0.57	42	Kentucky	300.40	0.11
17	Washington	369.55	0.48	43	Oklahoma	298.59	0.09
18	North Carolina	368.12	0.60	44	Wyoming	298.41	0.10
19	Alaska	364.67	0.47	45	Louisiana	298.30	0.09
20	California	358.46	0.45	46	North Dakota	298.10	0.05
21	South Carolina	357.31	0.58	47	Alabama	295.87	0.08
22	Texas	356.12	0.47	48	Iowa	295.85	0.05
23	Florida	355.14	0.48	49	South Dakota	290.85	0.05
24	Washington, DC	349.86	0.53	50	Utah	286.04	0.04
25	National	349.08	0.41	51	Arkansas	284.70	0.06
26	Colorado	342.10	0.29	52	Mississippi	280.59	0.04

Table 4 — 1995 Average SAT Scores
Ranked by State - Residual Method

Rank	State	Ave	p	Predict	r	Rank	State	Ave	p	Predict	r
1	North Dakota	592	0.05	547.68	44.317	27	Rhode Island	463	0.70	462.09	0.911
2	Minnesota	579	0.09	542.42	36.584	28	Virginia	468	0.65	468.67	-0.673
3	Iowa	583	0.05	547.68	35.317	29	Pennsylvania	461	0.70	462.09	-1.089
4	Wisconsin	572	0.09	542.42	29.584	30	Alaska	489	0.47	492.38	-3.376
5	Connecticut	477	0.81	447.60	29.396	31	Alabama	538	0.08	543.73	-5.733
6	New Hampshire	491	0.70	462.09	28.911	32	Oklahoma	536	0.09	542.42	-6.416
7	Massachusetts	477	0.80	448.92	28.079	33	Louisiana	535	0.09	542.42	-7.416
8	Illinois	560	0.13	537.15	22.852	34	Ohio	515	0.23	523.98	-8.980
9	New York	473	0.74	456.82	16.178	35	Mississippi	540	0.04	549.00	-9.000
10	Hawaii	482	0.67	466.04	15.961	36	New Mexico	530	0.11	539.78	-9.782
11	New Jersey	478	0.70	462.09	15.911	37	California	485	0.45	495.01	-10.010
12	South Dakota	563	0.05	547.68	15.317	38	Indiana	467	0.57	479.21	-12.208
13	Kansas	557	0.09	542.42	14.584	39	Wyoming	525	0.10	541.10	-16.099
14	Utah	563	0.04	549.00	14.000	40	Kentucky	522	0.11	539.78	-17.782
15	Nebraska	556	0.09	542.42	13.584	41	National	482	0.41	500.28	-18.277
16	Oregon	499	0.51	487.11	11.891	42	Texas	474	0.47	492.38	-18.376
17	Montana	536	0.21	526.61	9.386	43	Georgia	448	0.65	468.67	-20.673
18	Michigan	549	0.11	539.78	9.218	44	North Carolina	454	0.60	475.26	-21.257
19	Maryland	479	0.64	469.99	9.010	45	Florida	469	0.48	491.06	-22.059
20	Missouri	550	0.09	542.42	7.584	46	Arizona	496	0.27	518.71	-22.713
21	Vermont	472	0.68	464.72	7.277	47	Arkansas	523	0.06	546.37	-23.366
22	Tennessee	543	0.12	538.47	4.535	48	Idaho	511	0.15	534.52	-23.515
23	Maine	469	0.68	464.72	4.277	49	Nevada	483	0.30	514.76	-31.762
24	Delaware	468	0.68	464.72	3.277	50	South Carolina	443	0.58	477.89	-34.891
25	Washington	494	0.48	491.06	2.941	51	Washington DC	445	0.53	484.48	-39.475
26	Colorado	518	0.29	516.08	1.921	52	West Virginia	484	0.17	531.88	-47.881

CONCLUSIONS

It is obvious that the participation rate dramatically affects the average SAT scores for each state. This is substantiated by the following statement made by The College Entrance Examination Board (2), "The most significant factor in interpreting SAT scores is the proportion of eligible students taking the exam — the participation rate." The College Entrance Examination Board (2) also substantiates our claim that only the academically best students take the SAT by stating, "Typically, these students have strong academic backgrounds and are applying to the nation's most selective colleges and scholarship programs." Based on the three different types of analysis done on the original data, it seems as though the residual method yields the most convincing results. It is clear that ranking states based solely on the average SAT scores is not a logical or fair system. There are many other factors besides the participation rate that can affect the average SAT score for a state. One can take into account factors such as teacher salaries, amount of money available per student, use of study aids, teacher/student ratio, average income per state, gender, and race. The College Entrance Examination Board (2) says, "Your SAT score is a better prediction of your income, race or gender than it is of your ability to perform in college."

REFERENCES

1. The College Board. (1996). *Number of SAT Candidates with Verbal and Math Mean Scores and Standard Deviations — National and for each State 1972 through 1995.* New York.

2. College Entrance Examination Board. (1996). Princeton, New Jersey.

3. Powell, Brian and Steelman, Lala Carr (1996). "Bewitched, Bothered, and Bewildering: The Use and Misuse of State SAT and ACT Scores." *Harvard Educational Review*, Vol. 66, No. 1, Spring 1996.

INTERVAL-CENSORED TYPE II PLAN: AVERAGE TIME TAKEN TO EXECUTE THE PLAN

Surekha Mudivarthy* and M. Bhaskara Rao,
Department of Statistics, North Dakota State University, P.O. Box 5575, Fargo, ND 58105

1. Introduction The Type II plan is used on many occasions in order to estimate the lifetime distribution of a product under investigation. Begin the plan by choosing two positive integers $r \leq n$. Select a sample of n units of the product, set them to work, and observe the units continuously until r units fail. The objective is to estimate the lifetime distribution of the product using the data on r failure times.

We want to offer a modification of this plan in response to a past consultation problem. This problem arose from two diverse fields: one from engineering and the other from ornithology. In order to save money in observing the units round the clock for the r units failure times, only periodic inspections are to be made. In such a plan, the exact failure times of the r units will be unknown, but we will know how many units failed between each of the consecutive inspection times.

Formally, the inspection plan can be described as follows. Choose and fix a number $t_0 > 0$. Select a sample of n units and set them to work. Inspect the units at times $t_0, 2t_0, \ldots$ until r units fail. Let M denote the number of inspections needed. Let X_i =Number of units that fail during the ith inspection interval $((i-1)t_0, it_0]$, i = 1,2,3,... . The data consist of M, X_1, X_2, ..., X_M. These random variables satisfy the following conditions:

$$X_1 + X_2 + \ldots + X_{M-1} \leq r - 1, \text{ and}$$
$$X_1 + X_2 + \ldots + X_M \geq r.$$

We call this plan Interval-Censored Type II plan. The basic questions we were asked to address were:
1. Evaluate the loss of information in some meaningful way if one adopts the Interval-Censored Type II plan over the traditional Type II plan;
2. Provide some guidelines as to the choice of t_0.
3. Provide some guidelines as to the choice of r.
4. Compute the average time taken to execute the Type II plan and Interval-Censored Type II plan for given values of r and to.

In this paper, we will focus on the last question . This is an ongoing work and we want to report a part of what we have achieved so far. Let T be the underlying lifetime variable associated with the product. We assume that T has an exponential distribution with unknown parameter $\theta > 0$. The probability density function of T is given by

$$f_\theta(x) = \theta \exp(-\theta x), x > 0, \theta > 0.$$

Let $T_1, T_2, \ldots, T_n$ be *iid* random variables with common probability density function the same as that of T. Let $T_{(1)} < T_{(2)} < \ldots < T_{(n)}$ be the order statistics of $T_{(1)}$, $T_{(2)}$, ..., $T_{(n)}$. Under the Type II plan, the data consist of the first r order statistics $T_{(1)} < T_{(2)} < \ldots < T_{(r)}$. The average time taken to execute the Type II plan is given by .

$$E_\theta(T_{(r)}) = \frac{1}{\theta} \sum_{i=1}^{r} \frac{1}{n-i+1} \qquad (1)$$

(See Epstein and Sobel (1953)). The average time taken to execute the Interval-Censored Type II plan is given by

$$t_0 E_\theta(M). \qquad (2)$$

We compute (1) and (2) for a number of values of θ , n, r and t_0

2. Distribution of M The distribution of M can be computed explicitly for given values of r, n, t_0, and n. Note that,

$$Pr_\theta(M=1) = Pr_\theta(X_1 \geqq r) = Pr_\theta \text{ (at least } r \text{ failures in the interval } (0,t_0])$$

$$= \sum_{x=r}^{n} \binom{n}{r} \left(1-e^{-\theta t_0}\right)^x \left(e^{-\theta t_0}\right)^{n-x} = \int_0^{p_1} \frac{1}{B(r,n-r+1)} z^{r-1}(1-z)^{n-r}\,dz = I_{p_1}(r,n-r+1),$$

where and is the Incomplete Beta Function. (Abramowitz and Stegun (1965)

For $m \geqq 2$,

$$Pr_\theta(M=m) = Pr_\theta(X_1+X_2+\ldots+X_{m-1} \leqq r-1 \text{ and } X_1+X_2+\ldots+X_m \geq r)$$

$$= \sum_{s=0}^{r-1} \sum_{t=r-s}^{n-s} Pr_\theta \text{ (} s \text{ units fail in the interval } (0,(m-1)t_0] \text{ and } t \text{ units fail in the interval } ((m-1)t_0, mt_0])$$

$$= \sum_{s=0}^{r-1} \sum_{t=r-s}^{n-s} \frac{n!}{s!t!(n-s-t)!} \left(1-e^{-\theta(m-1)t_0}\right)^s \left(e^{-\theta(m-1)t_0} - e^{-\theta m t_0}\right)^t \left(e^{-\theta m t_0}\right)^{n-s-t}$$

$$= \sum_{s=0}^{r-1} \frac{n!}{s!(n-s)!} \left(1-e^{-\theta(m-1)t_0}\right)^s \left(e^{-\theta(m-1)t_0}\right)^{n-s} \bullet \sum_{t=r-s}^{n-s} \frac{(n-s)!}{t!(n-s-t)!} \left(1-e^{-\theta t_0}\right)^t \left(e^{-\theta t_0}\right)^{n-s-t}$$

$$= \sum_{s=0}^{r-1} \frac{n!}{s!(n-s)!} p_{m-1}^s \left(1-p_{m-1}\right)^{n-s} I_{p_1}(r-s,n-r+1),$$

where $p_i = \left(1-e^{-\theta i t_0}\right)$, $i=1,2,\ldots$.

Using computer, the distribution of M is evaluated for a range of values of r, t_0, n and θ . The average time taken to execute the interval-censored type II plan is also computed for the same range of values. These are reported in the tables presented in the next few pages under the title (CP) along with the average time (FP) taken to execute the type II plan.

3. Conclusions It is to be expected that the average time taken to execute the interval-censored type II plan to be greater than that under the type II plan. The question is whether or not the average times differ substantially. Look at the case: n = 30, r = 10, θ = 1 day, and t_0 = 1. With probability 0.99977, one inspection will do to realize 10 failures and with probability 0.00023, two inspections are needed to realize 10 failures. Consequently, E(M) = 1.00023 and the average time taken to execute the interval-censored type II plan is given by t_0E(M) = 1.00023 days. On the other hand, if we adopt the type II plan for data collection, on the average it takes 0.39725 days to observe the 10-th failure. In the interval-censored type II plan, we are waiting for one full day to make the first inspection and one would expect to have 10 failures occur much earlier before the day is over. As one looks at the tables, one would realize that the average times are not substantially different, but, think of the money one would save by the periodic inspections plan.

References

1. Abramowitz, M., and Stegun, I.A. (1965) Handbook of Mathematical Functions, Dover Publications, New York.
2. Epstein, B., and Sobel, M. (1953) Life Testing, J. Amer. Stat. Assoc., 48, 486-502.

AVERAGE TIME TAKEN TO EXECUTE INTERVAL-CENSORED TYPE II PLAN (CP) AND TYPE II PLAN (FP)

θ = 0.1 and n = 10

\ t_0	5		10		15		20	
r\	CP	FP	CP	FP	CP	FP	CP	FP
3	5.9	3.4	10.1	3.4	15.0	3.4	20.0	3.4
4	7.2	4.8	10.4	4.8	15.1	4.8	20.0	4.8
5	8.9	6.5	11.2	6.5	15.2	6.5	20.0	6.5
6	11.0	8.5	13.0	8.5	15.8	8.5	20.1	8.5
7	13.5	11.0	15.7	11.0	17.5	11.0	20.7	11.0
8	16.8	14.3	19.3	14.3	21.1	14.3	22.9	14.3

θ = 0.1 and n = 20

\ t_0	5		10		15		20	
r\	CP	FP	CP	FP	CP	FP	CP	FP
6	5.7	3.5	10.0	3.5	15.0	3.5	20.0	3.5
8	7.3	5.0	10.1	5.0	15.0	5.0	20.0	5.0
10	9.3	6.7	10.8	6.7	15.0	6.7	20.0	6.7
12	11.3	8.8	13.0	8.8	15.3	8.8	20.0	8.8
14	14	11.5	16.6	11.5	17.1	11.5	20.3	11.5
16	17.7	15.1	20.4	15.1	22.1	15.1	22.5	15.1

θ = 0.1 and n = 30

\ t_0	5		10		15		20	
r\	CP	FP	CP	FP	CP	FP	CP	FP
10	5.98	4.0	10.0	4.0	15.0	4.0	20.0	4.0
15	9.45	6.8	10.5	6.8	15.0	6.8	20.0	6.8
20	13.1	10.7	15.8	10.7	15.8	10.7	20.0	10.7
25	19.6	17.1	22.0	17.1	25.4	17.1	24.3	17.1

θ = 0.1 and n = 40

\ t_0	5		10		15		20	
r\	CP	FP	CP	FP	CP	FP	CP	FP
10	5.1	2.8	10.0	2.8	15.0	2.8	20.0	2.8
15	6.7	4.6	10.0	4.6	15.0	4.6	20.0	4.6
20	9.6	6.8	10.3	6.8	15.0	6.8	20.0	6.8
25	12.0	9.6	13.9	9.6	15.1	9.6	20.0	9.6
30	16.0	13.5	19.3	13.5	19.0	13.5	20.3	13.5

θ = 0.1 and n = 60

\ t_0	5		10		15		20	
r\	CP	FP	CP	FP	CP	FP	CP	FP
20	5.7	4.0	10.0	4.0	15.0	4.0	20.0	4.0
30	9.8	6.9	10.1	6.9	15.0	6.9	20.0	6.9
40	13.4	10.8	16.6	10.8	15.3	10.8	20.0	10.8
50	20.0	17.5	21.8	17.5	22.2	17.5	23.6	17.5

θ = 0.2 and n = 10

\ t_0	1		5		9	
r\	CP	FP	CP	FP	CP	FP
3	2.2	1.7	5.0	1.7	9.0	1.7
4	2.9	2.4	5.2	2.4	9.0	2.4
5	3.7	3.2	5.6	3.2	9.0	3.2
6	4.7	4.2	6.5	4.2	9.2	4.2
7	6.0	5.5	7.9	5.5	9.6	5.5
8	7.6	7.2	9.7	7.2	11.0	7.2

θ = 0.2 and n = 20

\ t_0	1		5		9	
r\	CP	FP	CP	FP	CP	FP
6	2.2	1.7	5.0	1.7	9.0	1.7
8	3.0	2.5	5.1	2.5	9.0	2.5
10	3.8	3.3	5.4	3.3	9.0	3.3
12	4.9	4.4	6.5	4.4	9.0	4.4
14	6.2	5.7	8.3	5.7	9.3	5.7
16	8.1	7.6	10.2	7.6	11.0	7.6

θ = 0.2 and n = 30

\ t_0	1		5		9	
r\	CP	FP	CP	FP	CP	FP
10	2.5	2.0	5.0	2.0	9.0	2.0
15	3.9	3.4	5.2	3.4	9.0	3.4
20	5.8	5.3	7.9	5.3	9.1	5.3
25	9.1	8.6	11.0	8.6	12.4	8.6

θ = 0.2 and n = 40

\ t_0	1		5		9	
r\	CP	FP	CP	FP	CP	FP
10	1.9	1.4	5.0	1.4	9.0	1.4
15	2.8	2.3	5.0	2.3	9.0	2.3
20	3.9	3.4	5.2	3.4	9.0	3.4
25	5.3	4.8	7.0	4.8	9.0	4.8
30	7.3	6.8	9.7	6.8	9.5	6.8

θ = 0.2 and n = 60

\ t_0	1		5		9	
r\	CP	FP	CP	FP	CP	FP
20	2.5	2.0	5.0	2.0	9.0	2.0
30	3.9	3.4	5.1	3.4	9.0	3.4
40	5.9	5.4	8.3	5.4	9.0	5.4
50	9.3	8.8	10.9	8.8	12.7	8.8

θ = 0.5 and n = 10

\ t_0	1		2		3		4	
r\	CP	FP	CP	FP	CP	FP	CP	FP
3	1.2	0.7	2.0	0.7	3.0	0.7	4.0	0.7
4	1.4	1.0	2.1	1.0	3.0	1.0	4.0	1.0
5	1.8	1.3	2.2	1.3	3.0	1.3	4.0	1.3
6	2.2	1.7	2.6	1.7	3.2	1.7	4.0	2.6
7	2.7	2.2	3.1	2.2	3.5	2.2	4.1	2.2
8	3.4	2.9	3.9	2.9	4.2	2.9	4.6	2.9

θ = 0.5 and n = 20

\ t_0	1		2		3		4	
r\	CP	FP	CP	FP	CP	FP	CP	FP
6	1.2	.7	2.0	0.7	3.0	0.7	4.0	0.7
8	1.5	1.0	2.0	1.0	3.0	1.0	4.0	1.0
10	1.9	1.3	2.2	1.3	3.0	1.3	4.0	1.3
12	2.3	1.8	2.6	1.8	3.1	1.8	4.0	1.8
14	2.8	2.3	3.3	2.3	3.4	2.3	4.0	2.3
16	3.5	3.0	4.1	3.0	4.4	3.0	4.5	3.0

θ = 0.5 and n = 30

\t₀ r\	1		2		3		4	
	CP	FP	CP	FP	CP	FP	CP	FP
10	1.2	.8	2.4	8	3.0	8	4.0	8
15	1.9	1.4	4.1	1.4	3.0	1.4	4.0	1.4
20	2.6	2.1	8.5	2.1	3.2	2.1	4.0	2.1
25	3.9	3.4	17.2	3.4	5.1	3.4	4.9	3.4

θ = 0.5 and n = 60

\t₀ r\	1		2		3		4	
	CP	FP	CP	FP	CP	FP	CP	FP
20	1.2	0.8	2.0	0.8	3.0	0.8	4.0	0.8
30	1.8	1.4	2.0	1.4	3.0	1.4	4.0	1.4
40	2.7	2.2	3.2	2.2	3.1	2.2	4.0	2.2
50	4.0	3.5	4.4	3.5	5.4	3.5	4.7	3.5

θ = 1.0 and n = 20

\t₀ r\	0.5		1.0		1.5		2.0	
	CP	FP	CP	FP	CP	FP	CP	FP
3	0.6	0.4	1.0	0.4	1.5	0.4	2.0	0.4
4	0.7	0.5	1.0	0.5	1.5	0.5	2.0	0.5
5	0.9	0.7	1.1	0.7	1.5	0.7	2.0	0.7
6	1.1	0.9	1.3	0.9	1.5	0.9	2.0	0.9
7	1.4	1.2	1.7	1.2	1.7	1.2	2.0	1.2
8	1.8	1.5	2.1	1.5	2.2	1.5	2.3	1.5

θ = 1.0 and n = 40

\t₀ r\	0.5		1.0		1.5		2.0	
	CP	FP	CP	FP	CP	FP	CP	FP
10	0.5	0.3	1.0	0.3	1.5	0.3	2.0	0.3
15	0.7	0.5	1.0	0.5	1.5	0.5	2.0	0.5
20	1.0	0.7	1.0	0.7	1.5	0.7	2.0	0.7
25	1.2	1.0	1.4	1.0	1.5	1.0	2.0	1.0
30	1.6	1.4	1.9	1.4	1.9	1.4	2.0	1.4

θ = 2.0 and n = 10

\t₀ r\	0.25		0.5		0.75		1.0	
	CP	FP	CP	FP	CP	FP	CP	FP
3	0.30	0.17	0.50	0.17	0.75	0.17	1.0	0.17
4	0.40	0.24	0.52	0.24	0.75	0.24	1.0	0.24
5	0.45	0.32	0.56	0.32	0.76	0.32	1.0	0.32
6	0.55	0.42	0.65	0.42	0.79	0.42	1.0	0.42
7	0.67	0.55	0.79	0.55	0.88	0.55	1.04	0.55
8	0.84	0.72	0.97	0.72	1.05	0.72	1.14	0.72

θ = 2.0 and n = 30

\t₀ r\	0.25		0.5		0.75		1.0	
	CP	FP	CP	FP	CP	FP	CP	FP
10	0.30	0.20	0.50	0.20	0.75	0.20	1.0	0.20
15	0.47	0.34	0.52	0.34	0.75	0.34	1.0	0.34
20	0.66	0.53	0.79	0.53	0.79	0.53	1.0	0.53
25	0.98	0.86	1.10	0.86	1.30	0.86	1.21	0.86

θ = 0.5 and n = 40

\t₀ r\	1		12		3		4	
	CP	FP	CP	FP	CP	FP	CP	FP
10	1.1	0.6	2.0	0.6	3.0	0.6	4.0	0.6
15	1.4	0.9	2.0	0.9	3.0	0.9	4.0	0.9
20	1.9	1.4	2.1	1.4	3.0	1.4	4.0	1.4
25	2.4	1.9	2.8	1.9	3.0	1.9	4.0	1.9
30	3.2	2.7	3.9	2.7	3.8	2.7	4.1	2.7

θ = 1.0 and n = 10

\t₀ r\	0.5		1.0		1.5		2.0	
	CP	FP	CP	FP	CP	FP	CP	FP
3	0.6	0.3	1.0	0.3	1.5	0.3	2.0	0.3
4	0.7	05	1.0	0.5	1.5	0.5	2.0	0.5
5	0.9	0.7	1.1	0.7	1.5	0.7	2.0	0.7
6	1.1	0.9	1.3	0.9	1.6	0.9	2.0	0.9
7	1.4	1.1	1.6	1.1	1.8	1.1	2.1	1.1
8	1.7	1.4	1.9	1.4	2.1	1.4	2.3	1.4

θ = 1.0 and n = 30

\t₀ r\	0.5		1.0		1.5		2.0	
	CP	FP	CP	FP	CP	FP	CP	FP
10	0.6	0.4	1.0	0.4	1.5	0.4	2.0	0.4
15	1.0	0.7	1.1	0.7	1.5	0.7	2.0	0.7
20	1.3	1.1	1.6	1.1	1.6	1.1	2.0	1.1
25	2.0	1.7	2.2	1.7	2.5	1.7	2.4	1.7

θ = 1.0 and n = 60

\t₀ r\	0.5		1.0		1.5		2.0	
	CP	FP	CP	FP	CP	FP	CP	FP
20	0.6	0.4	1.0	0.4	1.5	0.4	2.0	0.4
30	1.0	0.7	1.0	0.7	1.5	0.7	2.0	0.7
40	1.3	1.1	1.7	1.1	1.5	1.1	2.0	1.1
50	2.0	1.8	2.2	1.8	2.7	1.8	2.4	1.8

θ = 2.0 and n = 20

\t₀ r\	0.25		0.5		0.75		1.0	
	CP	FP	CP	FP	CP	FP	CP	FP
6	0.3	0.17	0.5	0.17	0.75	0.17	1.0	0.17
8	0.4	0.25	0.51	0.25	0.75	0.25	1.0	0.2
10	0.5	0.33	0.54	0.33	0.75	0.33	1.0	0.33
12	0.6	0.43	0.65	0.43	0.77	0.43	1.0	0.43
14	0.7	0.57	0.83	0.57	0.85	0.57	1.0	0.57
16	0.9	0.76	1.02	0.76	1.11	0.76	1.12	0.76

θ = 2.0 and n = 40

\t₀ r\	0.25		0.5		0.75		1.0	
	CP	FP	CP	FP	CP	FP	CP	FP
10	0.26	0.14	0.5	0.14	0.75	0.14	1.0	0.14
15	0.34	0.23	0.5	0.23	0.75	0.23	1.0	0.23
20	0.48	0.34	0.52	0.34	0.75	0.34	1.0	0.34
25	0.60	0.48	0.7	0.48	0.76	0.48	1.0	0.48
30	0.80	0.68	0.97	0.68	0.95	0.68	1.02	0.68

θ = 2.0 and n = 60

\ t_0	0.25		0.5		0.75		1.0	
r \	CP	FP	CP	FP	CP	FP	CP	FP
20	0.29	0.20	0.50	0.20	0.75	0.20	1.0	0.20
30	0.49	0.34	0.51	0.34	0.75	0.34	1.0	0.34
40	0.67	0.54	0.83	0.54	0.76	0.54	1.0	0.54
50	1.00	0.88	1.10	0.88	1.36	0.88	1.18	0.88

θ = 5.0 and n = 10

\ t_0	0.1		0.2		0.3		0.4	
r \	CP	FP	CP	FP	CP	FP	CP	FP
3	0.12	0.07	0.20	0.07	0.30	0.07	0.40	0.07
4	0.14	0.10	0.21	0.10	0.30	0.10	0.40	0.10
5	0.18	0.13	0.22	0.13	0.30	0.13	0.40	0.13
6	0.22	0.70	0.26	0.70	0.32	0.70	0.40	0.70
7	0.27	0.22	0.32	0.22	0.35	0.22	0.42	0.22
8	0.34	0.29	0.39	0.29	0.42	0.29	0.46	0.29

θ = 5.0 and n = 20

\ t_0	0.1		0.2		0.3		0.4	
r	CP	FP	CP	FP	CP	FP	CP	FP
3	0.1	0.07	0.2	0.07	0.3	0.07	0.40	0.07
4	0.15	0.09	0.2	0.09	0.3	0.09	0.40	0.09
5	0.19	0.13	0.22	0.13	0.3	0.13	0.40	0.13
6	0.23	0.18	0.26	0.18	0.31	0.18	0.40	0.18
7	0.28	0.23	0.33	0.23	0.34	0.23	0.41	0.23
8	0.35	0.30	0.41	0.30	0.44	0.30	0.45	0.30

θ = 5.0 and n = 30

\ t_0	0.1		0.2		0.3		0.4	
r \	CP	FP	CP	FP	CP	FP	CP	FP
10	0.12	0.08	0.20	0.08	0.30	0.08	0.40	0.08
15	0.19	0.14	0.21	0.14	0.30	0.14	0.40	0.14
20	0.26	0.21	0.32	0.21	0.32	0.21	0.40	0.21
25	0.39	0.34	0.44	0.34	0.51	0.34	0.49	0.34

θ = 5.0 and n = 40

\ t_0	0.1		0.2		0.3		0.4	
r \	CP	FP	CP	FP	CP	FP	CP	FP
10	0.10	0.05	0.20	0.05	0.30	0.05	0.40	0.05
15	0.14	0.09	0.20	0.09	0.30	0.09	0.40	0.09
20	0.19	0.13	0.21	0.13	0.30	0.13	0.40	0.13
25	0.24	0.19	0.28	0.19	0.30	0.19	0.40	0.19
30	0.32	0.27	0.39	0.27	0.30	0.27	0.41	0.27

θ = 5.0 and n = 60

\ t_0	0.1		0.2		0.3		0.4	
r \	CP	FP	CP	FP	CP	FP	CP	FP
20	0.29	0.08	0.50	0.08	0.75	0.08	1.0	0.08
30	0.49	0.14	0.51	0.14	0.75	0.14	1.0	0.14
40	0.27	0.22	0.83	0.22	0.76	0.22	1.0	0.22
50	0.40	0.35	1.09	0.35	1.36	0.35	1.18	0.35

θ = 10 and n = 10

\ t_0	0.05		0.10		0.15		0.20	
r \	CP	FP	CP	FP	CP	FP	CP	FP
3	0.06	0.03	0.10	0.03	0.15	0.03	0.20	0.03
4	0.07	0.05	0.10	0.05	0.15	0.05	0.20	0.05
5	0.09	0.07	0.11	0.07	0.15	0.07	0.20	0.07
6	0.11	0.09	0.13	0.09	0.16	0.09	0.20	0.09
7	0.14	0.11	0.16	0.11	0.18	0.11	0.20	0.11
8	0.17	0.14	0.19	0.14	0.21	0.14	0.23	0.14

θ = 10 and n = 20

\ t_0	0.05		0.10		0.15		0.20	
r \	CP	FP	CP	FP	CP	FP	CP	FP
6	0.06	0.04	0.10	0.04	0.15	0.04	0.20	0.04
8	0.07	0.05	0.10	0.05	0.15	0.05	0.20	0.05
10	0.09	0.07	0.11	0.07	0.15	0.07	0.20	0.07
12	0.11	0.09	0.13	0.09	0.15	0.09	0.20	0.09
14	0.14	0.12	0.17	0.12	0.17	0.12	0.20	0.12
16	0.18	0.15	0.20	0.15	0.22	0.15	0.23	0.15

θ = 10 and n = 30

\ t_0	0.05		0.10		0.15		0.20	
r \	CP	FP	CP	FP	CP	FP	CP	FP
10	0.06	0.04	0.10	0.04	0.15	0.04	0.20	0.04
15	0.10	0.07	0.11	0.07	0.15	0.07	0.20	0.07
20	0.13	0.11	0.16	0.11	0.16	0.11	0.20	0.11
25	0.20	0.17	0.22	0.17	0.26	0.17	0.24	0.17

θ = 10 and n = 40

\ t_0	0.05		0.10		0.15		0.20	
r \	CP	FP	CP	FP	CP	FP	CP	FP
10	0.05	0.03	0.10	0.03	0.15	0.03	0.20	0.03
15	0.07	0.05	0.10	0.05	0.15	0.05	0.20	0.05
20	0.10	0.07	0.10	0.07	0.15	0.07	0.20	0.07
25	0.12	0.10	0.14	0.10	0.15	0.10	0.20	0.10
30	0.16	0.14	0.19	0.14	0.19	0.14	0.20	0.14

θ = 10 and n = 60

\ t_0	0.05		0.10		0.15		0.20	
r \	CP	FP	CP	FP	CP	FP	CP	FP
20	0.06	0.04	0.10	0.04	0.15	0.04	0.20	0.04
30	0.10	0.07	0.10	0.07	0.15	0.07	0.20	0.07
40	0.13	0.11	0.17	0.11	0.15	0.11	0.20	0.11
50	0.20	0.18	0.22	0.18	0.27	0.18	0.24	0.18

A STATISTICAL DATA ANALYSIS FOR IDENTIFYING IMPORTANT FACTORS FOR MAXIMUM PRODUCTION OF DURUM WHEAT HAPLOIDS

Surekha Mudivarthy and M. Bhaskara Rao*
Department of Statistics, North Dakota State University, Fargo, ND 58105

1. **Introduction** The authors of this article were invited to analyze data stemming from an experiment involving intergeneric crosses of durum wheat and maize to recover durum wheat haploids at the USDA-ARS, Northern Science Laboratory, Fargo. The readers can contact Dr. Jauhar or Dr. Bommineni to obtain detailed information on the original experiments. Although their manuscript is in preparation for publication, the purpose of this presentation is to provide a detailed explanation of the data analysis carried out on their original data.

Tetraploid durum wheat (*Triticum turgidum;* 2n = 4x = 28; AABB genomes) evolved from two diploid wild grasses viz., *Triticum urartu* (2n = 14; AA) and *Aegilops speltoides* (2n = 14; BB). In the terminology of genetics, durum wheat is an allotetraploid (because it has two different genomes) with 28 chromosomes, where each genome donor contributed 14 chromosomes. When one pollinates a durum wheat using pollen from another durum wheat, the offspring will receive 14 chromosomes from the male parent (seven each from the A and B genomes), and 14 chromosomes from the female parent, again seven each from the A and B genomes. However, If one pollinates a durum wheat with maize (2n = 20) pollen, the offspring receives 14 chromosomes from the female parent (durum wheat) and 10 chromosomes from the male parent. Because of "incompatibility" between two sets of chromosomes in this intergeneric zygote, maize chromosomes are eliminated in subsequent cell divisions and only 14 chromosomes of the durum parent are retained in developing embryos, In other words, these embryos consist of half of the chromosome number of the durum parent and hence are called haploids. The caryopses (or fruits) carrying these small embryos lack proper nutrition to support their growth and, therefore, the embryos need to be cultured on artificial nutritional media to recover adult haploid plants. Because of a single set of chromosomes, most of these haploid plants are sterile. After doubling their chromosome number with chemicals, fertility is restored and the doubled haploids are highly useful in plant breeding to develop superior cultivars.

The basic question is whether or not the crossing of durum wheat with maize would lead to a successful formation of embryos. Which one of the seven durum wheat cultivars [Durox, Langdon (LDN), Lloyd, Medora, Monroe, Renville, and Vic] and three modified durum wheat cultivars [LDN-5D(5B), LDN-*Ph1b Ph1b,* and Cappelli-*Ph1c Ph1c*] in combination with pollen from one of the three maize cultivars [Early Sunglow, Golden Jubilee, and White Knight] would offer the most successful rate of embryo formation? As noted earlier, once the embryos are formed, they were nurtured *in vitro* to recover plantlets. Again the question is which combination of the cultivars confers the best advantage of getting plantlets from the embryos.

The data consist of proportions cross-classified according to two factors. The traditional analysis uses the Analysis of Variance (ANOVA) method after transforming the data by the *arc-sine* square root transformation. We suggested a new way of analyzing the data by fusing the logistic model with the usual ANOVA model. This new model helped to identify some factors critical for production of the durum wheat haploids.

2. **Experimental methods** Durum wheat and maize plants used in the experiment were grown in 12 cm diameter pots in the greenhouse at 22°C. The male stamens in the spikes of the durum plants were manually removed and covered with glycine bags until the female stigmas become feathery and receptive. After 2 to 4 days, the stigmas were dusted with maize pollen (called pollination) and again bagged. Five different post-pollination spray treatments were used to recover haploid embryos. The spray treatments were:

a. Control : Double distilled water
b. 75 mg/L GA_3 + 5 mg/L 2,4-D
c. 3 mg/L 2,4-D + 60 mg/L $AgNO_3$
d. 3 mg/L 2,4-D + 120 mg/L $AgNO_3$
e. 3 mg/L 2,4-D + 180 mg/L $AgNO_3$

(GA_3 = gibberellic acid; 2,4-D = 2,4-dichlorophenoxy acetic acid; $AgNO_3$ = silver nitrate.)

The spray treatments were given within 24 hours after pollination and continued for up to 16 days to promote the development of haploid embryos on the spikes.

After 16 days, the caryopses containing the haploid embryos were surface sterilized, and the embryos were aseptically isolated and placed on nutrient medium in a Petri dish. The isolated embryos were incubated for 4-6 weeks in the dark at 25°C. The embryos that developed leaves and small primary roots were transferred to a lighted incubator at 25°C for 1-4 weeks until they developed into green plantlets.

In Table 1, we have included the number of florets pollinated, frequency of embryos that resulted, and frequency haploid plants that grew out of the embryos. The data are cross-classified according to the treatment used and durum wheat cultivar employed. In Table 2, the same information as presented in Table 1 is given but the data are now cross-classified according to two factors: maize cultivar used and durum wheat cultivar used.

3. **Analysis** Treatment a (control) has not produced even a single embryo. The data pertaining to the control are completely eliminated from further analyses. Some summary statistics are collected.

(i) Total number of florets pollinated = 14, 272.
(ii) Total number of embryos recovered = 1,038 (7.27% of total number of florets)
(iii) Total number of embryos germinated = 140 (13.49% of total number of embryos)

After the usual *arc sine transformation,* the data yielded four ANOVA tables reproduced below.

ANOVA TABLE FOR THE DATA ON EMBRYOS RECOVERED

Source	DF	MSS	F-ratio
Treatments	3	0.0942	15.30*
Durum wheat	9	0.0195	3.17*

* significant with p-value < 0.01

ANOVA TABLE FOR THE DATA ON HAPLOIDS GERMINATED

Source	DF	MSS	F-ratio
Treatments	3	0.3103	1.69
Durum wheat	9	0.0873	0.48

ANOVA TABLE FOR THE DATA ON EMBRYOS RECOVERED

Source	DF	MSS	F-ratio
Maize	2	0.0011	0.35
Durum wheat	9	0.0144	4.55*

* significant with p-value < 0.01

ANOVA TABLE FOR THE DATA ON HAPLOIDS GERMINATED

Source	DF	MSS	F-ratio
Maize	2	0.0021	0.07
Durum wheat	9	0.0459	1.90

Some useful pointers emerge from the analyses. As far as nurturing embryos to let them grow into haploid plants, it makes no difference who the parents of the embryos were. The conclusion makes sense. The act of nurturing embryos to develop them into plants is similar to the act of letting a premature baby grow in an intensive care unit. The parentage has no significant effect on the outcome. When it comes to the formation of embryos, the treatments are significantly different. The durum wheat genotypes are also significantly different. The maize varieties have no bearing on the incidence of formation of embryos. Once we recognize that the durum wheat genotypes are significantly different, we need to identify those genotypes which confer a distinct advantage on the incidence of formation of embryos. The method of least significant differences can be used to sort out the wheat genotypes. In stead, we will introduce a model which is a combination of the logistic model and ANOVA model. Let p_{ij} be the probability of successful formation of an embryo under the i-th treatment and j-th durum wheat genotype. The treatments under focus are: b, c, d, and e. These are labeled as 1, 2, 3, and 4. The durum wheat genotypes are those listed in the introduction. These are labeled as 1, 2, ... , 10 in the order they are listed in the introduction. The model governing these probabilities is given by

$$\ln(p_{ij}/(1-p_{ij})) = \mu + \alpha_i + \beta_j$$

where μ is the general effect, α_i is the effect of the i-th treatment, and β_j is the effect of the j-th durum wheat genotype. One advantage of this model is that the treatments can be arranged in the order of the magnitudes of their influences or effects. A similar ordering is feasible for the durum wheat genotypes. There is one small problem with this model. The parameters of the model are not uniquely identifiable. In order to resolve the identity crisis, one can set one of the effects to be equal to zero and then proceed to estimate the remaining effects using the data. PROC GENMOD in the SAS environment provides all the estimates of the effects along with their standard errors. The output is reproduced below.

Estimates of Effects and Their Standard Errors Under the Logisitc Model:
The case of successful embryo formation (Treatments x Durum wheat)

Parameter	Estimate	Standard error
Intercept (μ)	-3.1069	0.1163*
Treatment b	-1.9678	0.1006*
Treatment c	-0.1326	0.0787
Treatment d	-0.1243	0.0803
Treatment e	0.0000	(This is the effect set equal to zero.)
Durum Wheat		
LDN	-0.2197	0.1634
Cappelli	-0.1382	0.1673
LDN-*ph1*	0.0000	(This is the effect set equal to zero.)
Vic	0.2025	0.1928
Medora	0.4179	0.1748*
Monroe	0.4862	0.2042*
LDN-5D(5B)	0.5260	0.1322*
Lloyd	1.1886	0.1254*
Durox	1.2303	0.1264*
Renville	1.5337	0.1402*

Estimates of Effects and Their Standard Errors Under the Logisitc Model:
The case of successful haploid plant germination (Treatments x Durum wheat)

Parameter	Estimate	Standard error
Intercept (μ)	-2.7865	0.4491*
Treatment b	-2.1549	0.4712*
Treatment c	-0.4852	0.2444
Treatment e	0.0000	(This is the effect set equal to zero.)
Treatment d	0.3211	0.2224
Durum Wheat		
Cappelli	-0.1306	0.6951
LDN *ph1*	0.0000	(This is the effect set equal to zero.)
LDN	0.3624	0.6356
Lloyd	0.7578	0.4706
Monroe	0.8126	0.6875
Durox	0.8410	0.4825
LDN-5D(5B)	1.1654	0.4731*
Renville	1.5637	0.5127*
Vic	2.2852	0.6552*
Medora	2.3080	0.5020*

Some useful pointers emerge from the above output. If we regard Treatment e as a standard with which we compare the effects of other treatments, Treatment b has an adverse effect on embryo formation and on germination exhibiting below par performance very much below the norm. If we regard LDN-*ph1b ph1b* as a standard, the wheats LDN-5D(5B), Renville, Vic, and Medora exhibit above par performance significantly above the norm on germination and Medora, Monroe, Lloyd, LDN-5D(5B), Durox and Renville on embryo formation. The conclusions drawn on embryo formation using the logistic-Anova model agrees more or less with those using the least significant difference method on grouping the durum wheat genotypes.

A similar analysis is performed on the phenomenon of embryo formation and germination for the data cross-classified according to maize and durum wheat cultivars used. The output is reproduced below.

Estimates of Effects and Their Standard Errors Under the Logisitc Model: The case of successful embryo formation (Maize x Durum wheat)

Parameter	Estimate	Standard error
Intercept (μ)	-3.0603	0.1133*
Maize		
Golden Jubilee	-0.3498	0.0774*
Early Sunglow	-0.1954	0.0710*
White knight	0.0000	(This is the effect set equal to zero.)
Durum Wheat		
Medora	-1.1775	0.1763*
Vic	-1.0500	0.1873*
LDN	-0.5702	0.1633*
Monroe	-0.3788	0.2032
Cappelli	-0.1873	0.1678
LDN-*ph1*	0.0000	(This is the effect set equal to zero.)
LDN-5D(5B)	0.3484	0.1330*
Renville	0.4009	0.1342*
Durox	0.7749	0.1260*
Lloyd	0.8736	0.1247*

Estimates of Effects and Their Standard Errors Under the Logisitc Model: The case of successful haploid plant germination (Maize x Durum wheat)

Parameter	Estimate	Standard error
Intercept (μ)	-3.3403	0.4709
Maize		
Early Sunglow	0.9472	0.2269*
Golden Jubliee	0.5197	0.2441
White Knight	0.0000	(This is the effect set equal to zero.)
Durum Wheat		
Cappelli	-0.2247	0.7401
LDN *ph1b*	0.0000	(This is the effect set equal to zero.)
Monroe	0.2995	0.7189
LDN	0.3821	0.6637
Durox	0.5431	0.4902
Lloyd	0.7399	0.4857
Renville	1.0212	0.5154
Vic	1.0518	0.6164
LDN-5D(5B)	1.3300	0.4937*
Medora	2.8317	0.5336*

If we treat White Knight as a standard with which to compare the performance of other maize varieties, Early Sunglow and Golden Jubilee have adverse effect on the formation of embryos but Early Sunglow has a positive effect on germination. If we treat LDN *ph1b ph1b* as a standard to compare other durum wheat genotypes, LDN-5D(5B), Renville, Durox, and Lloyd have positive effect on embryo formation and LDN-5D(5B) and Medora have positive effect on embryo germination.

4. **Conclusions** If we put all analyses together, the wheat line LDN-5D(5B) seems to work best for embryo formation as well as germination. As far as maize cultivars are concerned, there is no clear cut winner. All seem to be equally good. With regard to treatments, avoid treatment b. All other treatments are not significantly different from each other.

Reference Almouslem, A.B., Jauhar, P.P., Peterson, T.S., Bommineni, V.R., and Joppa, I.R. (1997) Durum Wheat Haploids with and without *Ph1*: Chromosome pairing between A and B genomes, a pre-print.

Table 1: Frequency of embryos and haploid plants obtained after pollination of durum wheat genotypes with maize (Treatment x Durum wheat)

Treat-ments	Cultivars and Lines									
	Durum	LDN	Lioyd	Medora	Monroe	Renville	Vic	LDN-5D(5B)	LDN-*Ph1b*	Cappelli
a:										
i	84	90	78	74	68	64	72	88	96	86
ii	0	0	0	0	0	0	0	0	0	0
iii	0	0	0	0	0	0	0	0	0	0
b:										
i	1272	984	978	3588	1066	2440	2656	494	92	116
ii	30	3	19	5	0	102	20	2	2	2
iii	0	0	0	0	0	2	0	0	0	0
c:										
i	812	498	654	190	134	178	138	738	808	440
ii	94	20	85	10	10	20	5	62	13	10
iii	7	0	5	5	1	3	2	6	0	0
d:										
i	412	570	528	252	156	196	182	928	838	972
ii	26	10	78	31	4	18	2	60	49	28
iii	11	2	7	11	0	0	1	12	2	0
e:										
i	627	896	892	52	108	242	156	956	668	560
ii	105	35	85	16	21	28	6	54	29	24
iii	7	2	16	7	2	3	3	10	3	2
Total 1	225	65	248	57	35	66	13	176	91	62
Total 2	25	4	28	23	3	16	6	28	5	2

i = number of florets pollinated;
ii = number of haploid embryos recovered ;
iii = number of green haploid plantlets;
Total 1 = total number of embryos
Total 2 = total numbers of plants .

Table 2: Frequency of embryos and haploid plants obtained after pollination of durum with maize (Durum wheat x Maize)

Male / Female	Early Sunglow			Golden Jubilee			White Knight		
	Florets	Embryo	Plants	Florets	Embryo	Plants	Florets	Embryo	Plants
Durm	1449	112	12	451	44	6	1223	99	7
LDN	718	9	0	17	17	3	1576	42	1
Lloyd	1038	80	24	65	65	0	1142	122	4
Medora	1318	16	7	2	2	0	2088	34	16
Monroe	328	27	2	6	6	1	160	2	0
Renville	292	13	0	38	38	5	1204	117	13
Vic	1356	16	0	13	13	5	988	14	1
LDN-5D(5B)	760	25	10	57	57	12	1782	94	6
LDN- *Ph1b*	802	38	2	2	23	0	776	30	3
Cappelli	583	24	0	18	18	0	801	20	2

CARNIVORE SCENT-STATION SURVEYS: STATISTICAL CONSIDERATIONS

Glen A. Sargeant* and Douglas H. Johnson

Department of Wildlife Ecology, University of Wisconsin,
226 Russell Labs, 1630 Linden Drive, Madison, WI 53706 (GAS)
and United States Geological Survey, Biological Resources Division,
Northern Prairie Science Center, 8711 37th St. SE, Jamestown, ND (DHJ)

Scent-station surveys are a popular method of monitoring temporal and geographic trends in carnivore populations. We used customary methods to analyze field data collected in Minnesota during 1986-93 and obtained unsatisfactory results. Statistical models fit poorly, individual carnivores had undue influence on summary statistics, and comparisons were confounded by factors other than abundance. We conclude that statistical properties of scent-station data are poorly understood. This fact has repercussions for carnivore research and management. In this paper, we identify especially important aspects of the design, analysis, and interpretation of scent-station surveys.

INTRODUCTION

Animal abundance is one appropriate measure for gauging the success of wildlife management, monitoring the status of threatened and endangered species, and determining the outcome of many experiments. Thus, estimates of abundance are among the most important information needs of wildlife managers. Unfortunately, many carnivores are cryptic, secretive, and occur at low density. Accurate estimates of abundance are seldom obtainable for such species, so indices of relative abundance often substitute (see species accounts in Novak et al. [1]). Carnivore scent-station surveys are one such index.

We used standard methods to analyze scent-station data collected in Minnesota during 1986-93. Although our data set was among the largest in existence, we were frustrated by inadequate sample sizes. The most popular statistical model for scent-station data fit poorly. Anomalous data had undue influence on summary statistics and affected results of statistical comparisons. To overcome these problems, we devised improved methods for using scent-station surveys to monitor temporal and geographic trends in carnivore populations.

The difficulties we encountered can be traced to a few key features of survey designs and methods of analysis. These include the spatial distribution of scent stations, the experimental unit chosen for analyses, the statistic used to summarize results, the statistical model underlying analyses, and confounding of statistical comparisons. In this paper, we discuss these aspects of the design and analysis of carnivore scent-station surveys. Our presentation will demonstrate the use of field data to resolve issues raised in this paper.

SURVEY METHODS

The carnivore survey conducted annually by the Minnesota Department of Natural Resources and the U.S. Fish and Wildlife Service was the source of field data for our presentation. Each scent station consisted of a 0.9-m diameter circle of smoothed earth with a scented lure placed at the center. Stations were grouped in lines to simplify data collection. Ten scent stations placed along an unpaved road at 480 m intervals comprised a line. Minimum spacing between lines was 5 km. Sampling was non-random, but 441 lines were distributed throughout the state. Each line was operated for one night each year between late August and mid-October, though not all lines were operated every year. Presence or absence of tracks was recorded, by species, at each station when it was checked the day after activation.

CHOOSING AN EXPERIMENTAL UNIT

Scent-station surveys vary in design. Sometimes stations are not grouped, as they were in Minnesota. The dispersion of stations should determine how stations are treated in analyses: in some cases, stations may reasonably be treated as independent samples; in others, they should be considered correlated samples or subsamples. Usually these issues are given inadequate consideration.

Closely spaced stations produce correlated data, but how far correlations extend is unknown. Stations placed too close to one another produce redundant data. Spacing stations more widely than necessary increases the cost of surveys and precludes intensive sampling of small areas. Subjective estimates of optimum spacing are inconsistent. Some investigators (e.g., Smith et al. [2]) have treated stations within 320 m of one another as independent samples. Others (e.g., Morrison et al. [3]) thought it necessary to separate stations by as much as 1.6 km. We have used variograms to show that correlations between stations often extend to 2000 m or more. Separating stations by this great a distance is seldom practical, so we have pursued the development of summary statistics and methods of analysis that are robust to correlations between stations.

SUMMARY STATISTICS

Results of scent-station surveys are almost always summarized by visitation rates (p_s = stations visited/stations operated). As a summary statistic, visitation rates have two serious deficiencies.

First, visitation rates are not directly related to abundance because each station has the capacity for only one detection. When visitation rates are high, many individual carnivores encounter stations that have already been visited. These additional visits have no effect on visitation rates. The result is a nonlinear relationship between visitation rate and abundance. The form of the curve is unknown, except for the y-intercept (0) and asymptote (y=1), so visitation rates can be used only to rank abundances.

Second, visitation rates are easily influenced by factors other than abundance, especially when sample sizes are small or visitation rates are low. These may include weather, season, human activity, or other factors that influence animal behavior. An ideal summary statistic would be robust to such effects. We will use examples to demonstrate the poor performance of visitation rates and present two alternative summary statistics: the proportion of lines that are visited (p_l) and the negative natural logarithm of the proportion of lines that are not visited ($-\ln[1-p_l]$).

STATISTICAL MODELS

For analytical convenience, some investigators treat stations as independent Bernoulli trials: a visit by one or more individuals of a species is a "success." This model leads naturally to convenient methods of analyzing binomial data, including logistic regression and log-linear models. The benefit of this approach is the ability to investigate variables that affect visitation probabilities of individual stations (e.g., habitat characteristics).

Aggregating stations into groups--lines, in our example--and treating each group as an experimental unit is a more conservative approach. Group visitation rates are treated as independent random samples from unknown distributions. This approach has been used by investigators (e.g., Roughton and Sweeny [4]) who were unwilling to assume stations were independent.

To our knowledge, the fit of the binomial model has never been tested. We devised a goodness-of-fit test and found the binomial distribution to be a poor model for visitation rates, but an adequate one for the proportion of lines with one or more stations visited.

STATISTICAL COMPARISONS

With few exceptions, statistical analyses of scent-station data have been limited to pairwise comparisons (e.g., of years, seasons, or geographic locations). Significant differences faithfully reflect changes in abundance only if other factors that affect visitation are relatively constant over time and through space. Some investigators are unaware of the possible confounding effect of other factors (e.g. weather). Most often, however, only two or three years of data are available and are inadequate for testing the significance of long-term trends. Long-term data sets and careful analysis are required for separating changes in abundance from changes in confounding factors. We advocate testing for trends by simple linear regression of rank-transformed data: the method is easy to apply and interpret and is robust to confounding.

SUMMARY

Scent-station surveys are widely viewed as an accurate and inexpensive means of simultaneously gaining reliable information about the distribution and relative abundance of several species of carnivores (Johnson and Pelton [5]). Whether a particular scent-station survey will meet these high expectations depends largely on how the following issues are resolved:

1) Sampling: How should stations be spatially distributed?
2) Response variables: Is p_s a suitable summary statistic?
3) Statistical models: The binomial distribution has convenient properties, but does it adequately describe field data?
4) Statistical comparisons: Are comparisons confounded by unidentified factors?

ACKNOWLEDGMENTS

We thank the Minnesota Department of Natural Resources, especially W. E. Berg, and the U.S. Fish and Wildlife Service for generously providing survey data. Funding for manuscript preparation was provided by the Northern Prairie Science Center and the Wisconsin Cooperative Wildlife Research Unit of the Biological Resources Division, U.S. Geological Survey, and by the Graduate School, Department of Wildlife Ecology, and College of Agriculture and Life Sciences at the University of Wisconsin—Madison.

LITERATURE CITED

1. Novak, M., Baker, J.A., Obbard, M.E. and Malloch, B., eds. (1987) Wild furbearer management and conservation in North America. Ontario Trapper's Association, North Bay, 1150 pp.

2. Smith, W.P., Borden, D.L. and Endres, K.M. (1994) Scent-station visits as an index to abundance of raccoons: an experimental manipulation. J Mammal 75, 637-647.

3. Morrison, D.W., Edmunds, R.M., Linscombe, G. and Goertz, J.W. (1981) Evaluation of specific scent station variables in northcentral Louisiana. Proc Annu Conf of Southeast Assoc Fish and Wildl Agencies 35, 281-291.

4. Roughton, R.D., and Sweeny. M.D. (1982) Refinements in scent-station methodology for assessing trends in carnivore populations. J Wildl Manage 46, 217-229.

5. Johnson, K.G., and Pelton, M.R. (1981) A survey of procedures to determine relative abundance of furbearers in the southeastern United States. Proc Annu Conf Southeast Assoc Fish Wildl Agencies 35, 261-272.

SYMPOSIUM: ASTRONOMY IN NORTH DAKOTA - FROM THE SOLAR SYSTEM TO THE UNIVERSE OF GALAXIES

RESEARCH IN ASTROPHYSICS AT THE UNIVERSITY OF NORTH DAKOTA: 1996 - 1997

Mark J. Henriksen*, Department of Physics, University of North Dakota, Grand Forks, ND 58202-7129

THE EFFECT OF A CLUSTER POTENTIAL ON THE STAR FORMATION AND MORPHOLOGY OF A DISK GALAXY

Joel Haugen*
Department of Physics, University of North Dakota, Grand Forks, ND 58203

SIMPLE SCALING IN GALAXIES AND DARK MATTER

Richard T. Hammond*
North Dakota State University, Physics Department, Fargo, North Dakota 58105 U.S.A.
Kwan-Wu Lai
Mail Stop 301-150, Jet Propulsion Lab, California Institute of Technology, Pasadena, CA 91109-8099
Rebecca K. Sundhagen
Physics Department, North Dakota State University

THE NORTH DAKOTA SPACE GRANT PROGRAM AND ASTRONOMICAL RESEARCH AT THE DEPARTMENT OF SPACE STUDIES, UNIVERSITY OF NORTH DAKOTA

Steven H. Williams*
Department of Space Studies, University of North Dakota

RESEARCH IN ASTROPHYSICS AT THE UNIVERSITY OF NORTH DAKOTA: 1996 - 1997

Mark J. Henriksen*, Department of Physics, University of North Dakota, Grand Forks, ND 58202-7129
mahenrik@plains.nodak.edu

A summary of the results of three projects involving physics students at UND is presented. These projects address three major topics in modern astrophysics: the dark matter content of the Universe, galaxy interactions and mergers, and the evolution of galaxies in clusters of galaxies.

I. The Effect of Magnetic Fields in Clusters of Galaxies on the Measurement of Ω

Perhaps the most significant discovery in astrophysics in this century is that the Universe is expanding. Answering the obvious question, "will it expand forever?", is a primary goal of modern cosmology. It is a simple question and the methodology used to obtain the answer is also simple; measure the current mass density in the Universe and compare it to that needed to exert a strong enough gravitational attraction on the most distant galaxies to halt their outward motion. The minimum density required to stop the expansion of the Universe at some future time is called the critical density (ρ_c). The parameter, Ω (= ρ/ρ_c), is an indication of the future of the Universe in the sense that if Ω >1 (<1) the Universe will be in contraction (expansion) within several "Hubble times" (the current age of the Universe). Significant and profound progress has been made in the past decade though it has turned out to be a difficult measurement to make with competing methods giving different answers. In this paper, I will show that magnetic fields in clusters of galaxies are intimately related to current measurements of Ω and may be the key to providing unification of measurements of Ω.

A cluster of galaxies is a collection a thousand or more galaxies held together by gravity. Most galaxies in fact reside in clusters; so to measure the mass density in these objects is the best way to sample the average mass density of the Universe. It was discovered over 60 years ago that the galaxies themselves do not have enough mass, deficient by a factor of ten, to exert a mutual gravitational force which is sufficient to bind them into a cluster. This was the first indication that the mass density of the Universe might be dominate by unseen or dark matter.

In the last 10 years, two methods have emerged as competitors in determining the density of matter within a cluster of galaxies. Both methods are consistent within a factor of 2-3, however, this difference is enough to have very interesting implications. The first method exploits the presence of a hot intracluster medium which permeates all clusters of galaxies. This medium consists of cold, primordial intracluster gas which has been heated to millions of Kelvins and mixed with interstellar material which was originally contained in the cluster galaxies and was subsequently lost to the intracluster medium. Late in the life of a cluster of galaxies, the hot atmosphere of the cluster reaches a stage where it is in hydrostatic equilibrium, much like the Sun's atmosphere, in which the inward pull of gravity on each layer of the atmosphere is balanced by the outward push of gas pressure. The application of hydrostatic equilibrium provides a direct measurement of the mass at each radius in the cluster by using observationally determined temperature and the density of the gas, which determine the gas pressure, at each radius. This method consistently results in a value of Ω around 0.2 - 0.3, indicating an open Universe.

The other method involves an effect called gravitational lensing which is a prediction of the theory of relativity in which the space around a massive object is curved so that light passing nearby follows a curved path. In this way, the massive object focuses the light from an object behind it producing multiple images and great arcs and arclets of light. The distribution of these images is then used to derive the mass distribution of the lensing object, the cluster of galaxies. The measured mass is the total mass which includes galaxies, hot intracluster medium, and dark matter (identical to that measured by hydrostatic equilibrium). This method produces a larger Ω which is generally consistent with 1, a "critical Universe" or the minimum density in which the expansion of the Universe will ultimately be halted. The problem we will address is why X-ray measurements give a smaller total masses then gravitational lensing studies. One possibility to reconcile the different values of Ω would emerge if magnetic fields, rather than the gas, within the intracluster medium provide the pressure support to balance gravity in the central region of the cluster. A look at hydrostatic equilibrium with a magnetic field indicates that the mass content can be higher without increasing the thermal pressure of the gas while still maintaining the balance between pressure and gravity.

$$\frac{d}{dr}[n(r)KT(r)+B(r)^2/8\pi]=G\frac{M(r)\rho}{r^2}$$

In this Equation, the first term is due to gas pressure and the second term is due to magnetic field pressure. To confirm or deny this hypothesis, we are analyzing hard X-ray observations of five clusters of galaxies in order to infer the mean magnetic field in the cluster gas.

The broad (2 - 60 keV) spectrum of the cluster gas is dominated by the hot thermal component. The continuum of the thermal component is given by $e^{-h\nu/kT}$ so that for $h\nu >> kT$, the thermal continuum will essentially cutoff at higher energy (≈ 20 keV). But there is a non-thermal component which will dominate at energies above the cutoff of the thermal component. And this component depends on the magnetic field strength. This hard X-ray emission (HEX) results from cosmic microwave background photons scattering to X-ray energies off of primary cosmic rays (relativistic electrons) through the inverse Compton effect. Several clusters have diffuse radio halos which are produced by synchrotron emission from the relativistic charged particles (primary cosmic rays) in the magnetic field in the cluster. The radio observations constrain the energy distribution of relativistic electrons which directly effects the resulting HEX spectrum. The following equation for the HEX inverse Compton flux (F_c) shows that a higher magnetic field results in lower X-ray emission so that an upper limit on the HEX sets a minimum mean magnetic field.

$$F_c(\epsilon) = A a_3(p)(kT)^{(p+6)/2} B^{(p+2)/2} \epsilon^{p/2} cm^2 s^1$$

The observed radio spectrum provides the spectral index, p, the normalization, A, a(p) is a numerical factor, B is the mean magnetic field, ε is the photon energy. Unfortunately, with the sensitivity of the currently available data, no hard X-ray emission was detected from any of the clusters. Table 1 gives the HEX (90% confidence) upper limits we measured on the HEX in the 20 - 60 keV energy band. These limits were derived by performing a spectral fit of two data sets from the Advanced Satellite for Astrophysics and Cosmology (ASCA) and the High Energy Astrophysical Observatory - 1 (HEAO- 1). The model fit consists of a thermal component, which is tightly constrained by the ASCA data, and a non-thermal power-law component, which is best constrained by the HEAO1 data. Also shown in the Table is the lower limit on the mean magnetic field calculated from the upper limits. They range from 0.1 - 0.5 micro Gauss. This is the mean field, an average over the entire cluster. But in most astrophysical applications, the gas density is low so that the magnetic field is said to be "frozen in" to the gas and has the same distribution as the gas. The intracluster gas distribution is typically described by the following radial distribution: $n/n_c = (1 + (r/a)^2)^{-3\beta/2}$ which is peaked in the center and decreases with radius. The central value of the magnetic field is calculated from the mean by using this equation for the magnetic field distribution with typical values for the radial profile (a = 0.250 Mpc, β = 0.66, and the nominal size of the emitting region, 1 Mpc = 3.26 million light years) are used to calculate the central magnetic field. The mass problem is primarily confined to the central region of the cluster. The gas pressure and magnetic field pressure are both calculated and shown in the Table. Since the magnetic field pressure is a lower limit, the possibility exists that the fields are strong enough to dominate gas pressure. A1367 is a case in which the magnetic field support is dominant over gas pressure. Because it's gas temperature is low, the thermal part of the spectrum cuts off at lower energies and the HEX is easier to constrain. More sensitive hard X- ray detectors should be able to place more sensitive contraints on the magnetic fields and for cooler clusters such as A1367, detect them.

Table 1

Cluster	HEX (ergs cm^{-2} sec^{-1})	<B> μGauss	B_c μG	n(10^{-3} cm^{-3})	T (keV)	Pg (10^{-12} dynes cm^{-2})	Pb(10^{-12} dynes cm^{-2})
A401	<8.0	>0.14	>5.4	3	8.2 - 9.3	46	>1.2
A754	<4.8	>0.17	>5.9	2	10.5-11.5	33	>1.4
A1367	<0.51	>0.91	>35.	0.7-1.2	3.4-4.2	6	>48.7
A2256	<1.1	>0.30	>10.5	2.4-2.5	5.3-6.0	22	>4.4
A2319	<4.8	>0.17	>5.9	2.9-3.3	9.0-10.5	48	>1.4

II. An X-ray Survey of Galaxy Pairs (in collaboration with Sarah Cousineau)

In the past several years, observational and theoretical work has highlighted the importance of galaxy interactions and mergers in galaxy evolution. Galaxy evolution over that past 5 - 10 billion years is characterized by: (1) a change in the overall distribution of galaxies from mostly spiral to mostly elliptical, (2) a very high rate of star formation in normal galaxies 5 billion years ago, (3) appearance of a special class of galaxies exhibiting an active nuclear region of intense star formation called "starburst galaxies". Normal galaxies can be organized into two morphological classes: spiral and elliptical. Thus, pairs of galaxies can be broken down into spiral pairs, elliptical pairs, and mixed pairs. By studying galaxies in close proximity, and making comparisons to isolated galaxies, we can study the nature of galaxy interactions and the origin of galaxy pairs.

1. Data

The largest sample of optically selected galaxy pairs has been assembled by Karachentsev (1) with nearly 600 entries. We have undertaken the first X-ray study of galaxy pairs using this sample. Since there has been no previous X-ray survey of pairs nor is there a suitable planned X-ray imaging instrument to carry out a survey of this size, we have looked for serendipitous appearances of galaxy pairs from the optical survey on the archived images from the ROSAT pointed X-ray observations of the Position Sensitive Proportional Counter (PSPC). The field of view of the images is a circle of radius 1 degree with an energy band of 0.25 - 2.0 keV, well suited to the soft X-ray emission from galaxies. Of the optical galaxy pairs, 57 were found to have coordinates which placed them on the X-ray images. The integration times ranged from several thousand seconds to several tens of thousands of seconds. Since they were not the primary target, in a number of cases, the galaxies fall in a region of low mirror/detector sensitivity. Consequently, in a number of cases the pairs were not detected and upper limits were measured.

We ran correlation tests between the luminosity in the blue part of the electromagnetic spectrum (L_b), which is sensitive to radiation from massive, young stars and is therefore evidence of current star formation, and soft X-ray emission (L_x), which is an indication of the amount of gas at millions of Kelvins, presumably interstellar gas or halo material heated by galactic winds driven by the star formation. This produces a correlation in isolated galaxies, $L_x \sim (L_b)^\alpha$, for both spiral and elliptical galaxies. Running the same correlation tests on isolated galaxies and pairs can indicate whether the relationship between star formation and hot gas is the same for galaxies in pairs.

2. Elliptical-Elliptical Pairs

There were 16 pairs of elliptical galaxies of which 10 were detected and 6 have upper limits. The blue luminosities of the galaxies range from 3.4×10^{43} - 5.4×10^{44} and the X-ray luminosities range from 10^{41} - 10^{44}. For this sample, a statistical fit to the data gave a strong correlation probability of 99%. This is consistent with the survey of isolated elliptical galaxies by Eskridge et al. (2), suggesting that the amount of star formation is correlated with the amount of hot gas in both systems. The correlation between star formation and the amount of hot gas may be an indication that a hot wind permeates the galaxy and is driven by the energy input from the star formation. This is possible because the most massive stars will become supernovae and release a large amount of energy heating the interstellar medium of the galaxy on a short time scale. An important difference is that the ellipticals in pairs exhibit a larger blue luminosity than do the isolated ellipticals. In addition, the correlation with blue luminosity is much steeper, so that for a given level of star formation, there is a much larger amount of hot gas, for galaxies in pairs. Indeed, the highest X-ray luminosities are atypical of isolated elliptical galaxies and are more typical of groups of galaxies and even the central regions of poor clusters of galaxies which are both dominated by hot intergalactic gas. We interpret this to mean that there is a second component of hot gas in the pairs. Small groups of three or more galaxies, have diffuse X-ray emission due to an intergalactic medium which is between the galaxies. These results suggest that the elliptical pairs have evolved from groups of galaxies which were dominated by spiral galaxies. The spiral galaxies merged to form elliptical galaxies, as been shown to be possible in recent simulations by Barnes and Hernquist (3). The violent process of merging and the star forming material from the spiral disks account for the increased rate of star formation in the paired ellipticals. The additional component of hot gas is the fossil remnant of the group's intergalactic medium. These results suggest that the general transformation of a spiral rich population of galaxies to one dominated by ellipticals may take place through galaxy mergers within groups of galaxies.

3. Spiral-Spiral Pairs

The spiral galaxy pairs showed a similarly strong correlation to that found for isolated spirals by Fabbiano et al. (4). The correlation is in fact statistically indistinguishable. The primary difference is that the spirals in pairs have blue luminosities and X-ray luminosities which place them at the extreme high end of the range of values of these parameters found for isolated spirals. This is interpreted as evidence that the spiral galaxies are interacting and inducing a higher rate of star formation and a more luminous hot phase of the interstellar medium through tidal interactions.

4. Mixed Pairs

Perhaps the least understood correlations involve galaxies in pairs with different masses; the mixed pairs. Elliptical galaxies are approximately a factor of 10 times more massive than spiral galaxies so that mass transfer may take place from the spiral to the elliptical. This is possible because the gravitational attraction from the elliptical galaxy on the material far out in the disk (~20 kpc) may be larger than the self-gravity of the spiral galaxy if the pair is close proximity (~60 kpc). The X-ray and blue luminosities do not show a correlation. The correlation seen for both spirals and ellipticals appears to break down because of a few pairs with high X-ray luminosity and a relatively low blue luminosity. The range in blue luminosity more closely resembles the range in blue luminosity of the spiral pairs rather than ellipticals. On the other hand, the very high X-ray luminosity may indicate a similar origin to the elliptical pairs; the merger may have been in the past giving a lower blue luminosity and the X-ray emission remains as a fossil remnant of the group the elliptical galaxy formed from. Perhaps the mixed pairs are the best evidence of pairs which have formed through the merger of galaxies within groups because they show the X-ray luminosities typical of the intergalactic medium of groups and in some cases show very little current star formation.

III. The Nature of the Unidentified Small Scale X-ray Structure in Clusters of Galaxies (in collaboration with Dean Smith).

Clusters of galaxies such as A1367 (the 1367th entry on Abell's historic and monumental optical catalog of galaxy clusters) show substructure in their X-ray image which is visible to the naked eye. Less than half of the clusters of galaxies have images in which the gas appears smooth and symmetric, indicative that the gas is in hydrostatic equilibrium. However, many clusters appear similar to A1367 showing a very asymmetric gas distribution and evidence of small scale substructure. Yet, when standard source detection algorithms are applied to the images, very few sources meet the detection criterion (typically 5σ). This is because the diffuse intergalactic medium provides a broad, nearly flat background of X-ray emission so that weak point and extended sources do not protrude out with sufficient significance. We have convolved a wavelet function with the image with the goal of amplifying the weak sources above the cluster intergalactic medium. For this purpose, a "Mexican Hat" was employed because it has negative value wings. Because of this, it amplifies structure with a similar scale size as the chosen wavelet. When the function is multiplied by a source which is larger than the wavelet, the convolution adds in negative emission from the negative valued wings (which contain source emission); this suppresses the overall strength of the source. If the source did not extend out into the wings, it would have been amplified rather than suppressed. Therefore, to find the structure on all scales requires convolving the image with wavelets which span the entire range of sizes of structure in the image. For clusters, wavelets with half-width of 10, 20, 40, 80, 160 arc secs are used. This method has proved superior for finding structure; in the central region of the A1367 image alone (approximately 20% of the available image), 33 sources were found with a significance greater than 3.5σ after the wavelet convolution. After using this method to locate the weak sources, detailed corrections were applied to correct for spurious counts from cosmic rays, vignetting within the detector and by the telescope, and removal of the galactic and extragalactic background components as well as the "contaminating" cluster emission, thus allowing an accurate measurement of the source count rate. Next we identified as many of the sources as is possible using the numerous, available catalogs of stellar and non-stellar sources. From these, we selected two subsets: (1) extended sources identified with galaxies in the A1367 cluster and (2) extended, non-stellar, sources with no counterparts. We checked their position on the Digital Sky Survey and they remain unidentified, extended (non-stellar) sources. Six sources were in the first sample and eighteen in the second.

Table 2

Source	Local Flux (10^{-12} ergs cm $^{-2}$ s^{-1})	Radius (arc min)	ID	Source	Local Flux (10^{-12} ergs cm $^{-2}$ s^{-1})	Radius (arc min)	ID
17	2.82	0.3	none	19	1.05	8.8	none
3	2.33	8.4	galaxy	5	0.93	5.6	galaxy
18	2.08	4.4	none	26	0.81	17.6	none
20	1.78	5.5	none	14	0.74	11.5	none
13	1.69	4.8	none	4	0.74	16.2	galaxy
8	1.64	11.2	galaxy	28	0.67	17.6	none
21	1.46	10.7	none	6	0.67	20.4	galaxy
16	1.3	15.8	none	9	0.55	15.2	galaxy
25	1.24	13.2	none	27	0.50	17.0	none
15	1.12	9.5	none	32	0.47	16.8	none
30	1.11	16	none	33	0.25	18.9	none
12	1.11	6.9	none	10	0.013	23.0	none

There are two possibilities for the origin of the unidentified sources. They may be material removed from individual or groups of galaxies or distant clusters of galaxies. Approximately 20-30% of the sources should be identified with distant clusters using previous serendipitous surveys such as the Einstein Medium Sensitivity Survey as a predictor. To determine whether the first possibility can account for most of the eighteen sources, we can test whether or not the sample of objects without counterparts reside in a more gas-rich cluster environment than those identified with galaxies. The local flux of X- ray emission surrounding the sources, if at the same distance, depends primarily on the gas density. This would test the hypothesis that they are elliptical galaxy halos or group intergalactic medium removed by the ram-pressure of the intracluster medium on the galaxies as they move through the medium. Conversion of the count rate to a flux for both entries allows us to derive a flux corrected for absorption. The column density of neutral hydrogen measured at the position of each source was used. The results are shown in Table 2. Examination of Table 2, which is ordered by flux (proportional to gas density), shows that there is no difference in gas density of environment between galaxies and unidentified sources. The mean values are identical (1.1×10^{-12}) and clearly do not support the hypothesis that the sources are primarily stripped material. After four more cluster fields are analyzed in a similar fashion, each sample (those identified with galaxies and those with no counterpart) should have approximately 50 - 100 entries making statistical studies an important diagnostic in identifying the sources. Deep optical imaging at a large telescope, will also provide answers to some of the questions surrounding these mysterious, and fascinating objects.

IV. Acknowledgments

This research is supported by grants from the National Science Foundation, NASA, and ND EPSCoR.

V. References

1. Karachentsev, K. (1972), in Catalog of Isolated Galaxy Pairs in the Northern Hemisphere
2. Eskridge, P.B., et al. (1995), ApJ, 448, 70.
3. Barnes, J., and Hernquist, L. (1993), Physics Today, 46, 54.
4. Fabbiano, G., Gioia, I.M., and Trinchieri, G. (1987), ApJ, 324, 749-766.

THE EFFECT OF A CLUSTER POTENTIAL ON THE STAR FORMATION AND MORPHOLOGY OF A DISK GALAXY

Joel Haugen*
Department of Physics, University of North Dakota
Grand Forks, ND 58203

I. INTRODUCTION

A galaxy is a huge, gravitationally bound conglomeration of stars and gas. Galaxies are dispersed throughout the universe in groupings called clusters. These clusters have a gravitational influence on nearby objects. Einstein proved that light can be bent by the gravity of massive objects. This is known as gravitational lensing because the gravity of the object bends and focuses the light, much as a glass lens does. A cluster of galaxies has enough mass within it to do this to light from a more distant galaxy or star. Based on this lensing phenomenon, astronomers can calculate the mass of the cluster of galaxies and derive a mass distribution equation for the cluster. This mass distribution equation gives the mass of the cluster within a certain radius from the center as if the mass of the cluster were uniform in space, and this mass gives a gravitational potential that acts on other galaxies. The mass distribution model for gravitational lensing is typical of the period of galaxy evolution, z=0.2 (1). Most of the galaxies are seen to have undergone evolution at this time period, which is about 5 billion years ago.

There are three main mechanisms by which galaxies are believed to evolve: interactions and mergers of individual galaxies, pressure from the surrounding interstellar medium, and tidal effects of the cluster potential. Individual galaxies that move through space merge together or have an influence on other close galaxies, changing the shapes and other characteristics of the galaxies. The interstellar medium is the gas and dust that is present in between the stars of a galaxy, in the space that most believe is a pure vacuum. This gas and dust exert a pressure upon itself and other clouds of gas and also the stars in the galaxies. There are also the tidal effects that clusters have on individual galaxies that are under the influence of the cluster. Clusters influence not only the light coming from the galaxies, but also the stars and gas within the galaxy through the strength of cluster's gravity, which depends on the mass enclosed within the cluster. This effect is the same as the tidal effect the moon has on the earth's oceans. These tidal effects will produce an increase in velocity of the orbiting gas clouds and stars in the galaxy. This increase acts in both the radial and tangential directions, and depends on the cluster mass distribution. The velocity increase will drive the clouds into collisions, increasing, in particular, the high-velocity collisions. The tidal effects will trigger collisions that will increase the expected level of star formation of the galaxy. Using the collisions of gas clouds as a mechanism for star formation, it is shown that, under the influence of a cluster potential, there is an increase in the star formation rate for a disk galaxy under the influence of a cluster potential.

The radial acceleration acts to stretch the galaxy, while tangential component tends to compress the galaxy. The magnitudes of these components depend on the cluster mass model that is used. Different cluster mass models will produce different accelerations. The results show a difference in morphology of the disk galaxy between the two mass models used: a standard King model with core radius 250kpc and a King model derived from gravitational lensing with a core radius of 50kpc, where 1 pc, or parsec, is 3.262 light-years and 1 kpc, or kilo-parsec, is 3262 light-years. One light-year is the distance light travels in one year and is equivalent to 9.46×10^{12} kilometers or 5.82 trillion miles.

II. METHODS AND MATERIALS

There are two main types of code used to perform N-body galaxy simulations: tree and mesh. In a general sense, mesh type codes are faster than the tree type, but they lack resolution near the center of the galaxy. What the mesh code does is to load the galaxy and the perturber (in this case, a cluster) into a Cartesian mesh, or rectangular or square grid. While this gives enough resolution near the edge of the galaxy and the area near the perturber, it lacks resolution near the center of the galaxy, where stars and gas clouds are packed close together. The code used in these simulations uses a polar-coordinate grid to load the galaxy and the perturber, which maintains the speed advantage over the tree code, while giving the wanted resolution near the center.

In the radial direction, the grid is spaced exponentially, increasing in resolution from edge to center, which is where the highest resolution is desired. In the angular direction, the grid is divided up into equal sections, each being 10 degrees. In this way, each bin created has an almost rectangular shape. The stars and gas clouds are loaded into these bins and are allowed to orbit the center of the galaxy, giving it a sense of rotation.

Each of the particles in the galaxy is moved by interpolating the forces acting on it from the 9 nearby bins. The last particle loaded into the grid is the perturber. The galaxy is modeled with self-gravity, thus the gravitational potential at each bin of the grid is calculated, along with the potential of the perturber and the halo component of the galaxy. In the potential calculation for the perturber, it is treated as an extended mass distribution. The center of mass of the system is held fixed during all of the simulations, while both the perturber and the galaxy are able to move.

Two different mass distribution functions were used during the simulations: a standard King model with a core radius of 250kpc, and a King model derived from gravitational lensing that has a core radius of 50kpc. Each model was normalized so that the mass within the cluster at a radius of 20 core radii from the center was equal to 1. This mass was then used in the calculation of the potential from the cluster. The scale factor in the program is arbitrary, so a scale of 4.158kpc per grid unit was adopted. The size of the galaxy is nominally 20kpc in radius, and the galaxy is started at a distance of 250kpc away from the center of the galaxy with no initial velocity. In the calculation of the potential from the cluster, the distance between the two centers is calculated, and this is converted to core radii by the following equation:

$$x = \frac{d_{cent}}{r_{core}}$$

where r_{core} is the size of the core radius in kilo-parsecs and d_{cent} is the distance between the center of the cluster and the center of the galaxy, also in kilo-parsecs.

This number of core radii, designated x in the following equation, then gives the mass of the cluster in solar masses. This is normalized and then used in the calculation for the potential of the halo. The mass distribution equation for the gravitational lens model, with core radius of 50kpc, and the standard King model, with core radius of 250kpc, is (2):

$$M = 0.3716 \cdot \ln(x + \sqrt{1+x^2}) + \frac{x}{\sqrt{1+x^2}}$$

The equation for both the mass distributions is the same due to the same normalization, but the models differ significantly in the size of their core radii.

The program did account for gas cloud collisions, which is assumed to be the only action that drives the star formation, but it did not check to see if any of the clouds formed stars upon colliding. Initially, neutral hydrogen clouds were investigated, with a desire to put in giant molecular clouds at a later time. The clouds already had a velocity dispersion that can be controlled by the Toomre Q factor, which is a parameter whose value determines the stability of the rotating galactic disk (3). A Q factor was chosen so that the disk was stable. A typical radius of 10 pc was used for the neutral hydrogen cloud, with a number density $n_{HI} = 30\ cm^{-2}$, and a mass of 280 solar masses.

The positions of the clouds were checked against those of the others. If a collision occurred, isothermal shock conditions were applied and the Jeans criterion was checked. The Jeans criterion is an application of the virial theorem. It gives a critical mass for a gravitationally bound cloud such that, if the mass of the cloud exceeds this critical mass, the cloud will eventually collapse under its own gravity. If all conditions are met, then each cloud is assumed to form a star. The Jeans equation is:

$$M_{cr} = 10\sqrt{\frac{3\pi}{32}} \cdot \frac{c^3}{\sqrt{G^3\rho}}$$

where ρ is the density, c is the sound speed, and G is the gravitational constant. Using typical interstellar parameters, this equation becomes (4):

$$M_{cr} = 1.2 \times 10^8 \frac{c_{10}^3}{\sqrt{n}}$$

where c_{10} is the sound speed in units of 10 km s^{-1}, and n is the number density of the cloud. This equation gives the critical mass in solar masses, or multiples of the sun's mass. The sound speed was calculated using an isothermal sound speed equation:

$$c = \sqrt{\frac{T_u}{10000}}$$

where T_u is the upstream gas temperature in Kelvin. Upstream applies to the cloud before the shock front has passed through it, while downstream applies to after the shock front has passed. This was then used to calculate the Mach number according to the formula:

$$M = \frac{vel_{up}}{c}$$

where vel_{up} is the relative upstream velocity of the clouds, and c is the sound speed. This gives a measure of the relative speed of the clouds with respect to the local sound speed. The Mach number is used to find the downstream density of the clouds, or the density after the shock wave has passed through them:

$$\rho_d = \rho_u \cdot M^2$$

Because an isothermal equation was used, there was no limit on the amount of compression that occurred in the cloud. In the equation, ρ_d is the downstream density while ρ_u is the upstream density. Higher compression leads to lower critical mass for neutral hydrogen clouds.

A similar formula was used for giant molecular clouds or GMCs. If the Jeans equation is used to calculate the critical mass for a giant molecular cloud, one sees that the mass of the cloud is already greater than the critical mass, inferring that the cloud should collapse. However, observations of the clouds point to the fact that they do not collapse. Thus, there must be some other support mechanism for the cloud. This support is given by the galactic magnetic field. The field permeates the whole galaxy and is constant throughout the cloud. The equation for GMCs is not the same as the equation for neutral hydrogen due to the magnetic field support of a GMC against gravitational collapse, which slows or even halts its collapse:

$$M_{cr} = 8.73 \times 10^{27} \cdot \frac{B^3}{\rho_d^{\,2}}$$

where B is the strength of the magnetic field, nominally 20×10^{-6} Gauss, and ρ_d is again the downstream number density. Only a few parameters needed to be changed for the GMC simulations. The radius of each cloud was changed to 40 pc and the density to 70 cm^{-2}, each a typical value. In the case of GMCs, an increase in compression also leads to a lower critical mass. The galactic magnetic field does not really affect the hydrogen clouds due to their electrical neutrality.

III. RESULTS AND DISCUSSION

Plots of the galaxy's shape were done at six different distances (all in kpc): 250, 200, 150, 100, 50, and 5~10. These were done for the both the lens cluster model, and for the King model.

The initial loading of the galaxy is circular and has a radius of approximately 20kpc, our nominal radius. This, and subsequent plots, are of the old stars in the galaxy, that is, the ones that were loaded at the start of the simulation. The plots show that, as the galaxy and the cluster approach each other, the shape of the galaxy changes drastically in both the x and y directions. Not only is the galaxy stretched in one direction, it is compressed in another and some of the stars are "pushed" away from the rest, scattering out behind the galaxy as it moves closer. The King model shows less shape change than does the lens model. To make a quantitative analysis of the shape change for either model, the major and minor axes of the galaxy were measured and the eccentricity of the galaxy was calculated. The galaxy initially starts with a circular shape with eccentricity of 0. As the galaxy follows its orbit, its shape changes to a more elliptical shape. This effect is noted by the change in the major and minor axes lengths and in the eccentricity seen in the following table. Table 1 shows the major and minor axes of the galaxy at different distances, models, and mass ratios. For the unperturbed galaxy, its shape will always be circular and have an eccentricity of 0, while an ellipse has an eccentricity ranging from 0 to 1. The greater the eccentricity, the more the galaxy is elliptical in shape and the more it has changed shape during its orbit.

mass	dist	model	b	a	e	model	b	a	e
10	200	lens	8.6	8.6	0.00	King	8	8.5	0.34
10	150	lens	8.5	8.7	0.21	King	8.9	9.1	0.21
10	100	lens	8.6	9.2	0.36	King	9	9.2	0.21
10	50	lens	8.9	9.2	0.25	King	9.1	9.3	0.21
10	5	lens	9	9.2	0.21	King	9.1	9.2	0.15
1000	200	lens	8.4	8.4	0.00	King	8.2	8.3	0.15
1000	150	lens	7.5	7.8	0.27	King	6.9	8	0.51
1000	100	lens	7	7.9	0.46	King	7.8	8.2	0.31
1000	50	lens	6.8	8	0.53	King	7.4	7.7	0.28
1000	14	lens	4.8	7.7	0.78	King	7.4	7.4	0.00
10000	200	lens	8.1	8.2	0.16	King	7.7	8.7	0.47
10000	150	lens	7	8.5	0.57	King	7.1	8.3	0.52
10000	100	lens	5	8.1	0.79	King	6.9	8	0.51
10000	50	lens	4.5	7	0.77	King	7.6	8.2	0.38
10000	5	lens	5	8	0.78	King	7.6	7.8	0.22
100000	200	lens	8.2	8.3	0.15	King	8.3	8.4	0.15
100000	150	lens	6.1	8.2	0.67	King	8.1	8.3	0.22
100000	100	lens	5.8	8.7	0.75	King	8.4	8.4	0.00
100000	50	lens	4.7	8.1	0.81	King	8.2	8.7	0.33
100000	5	lens	—	—	—	King	7.8	8.3	0.34

Table 1

Column 1 is the cluster-to-disk mass ratio

Column 2 is the distance from the center of the galaxy to the center of the cluster

Columns 3 and 7 are the types of mass distribution functions used for that run

Columns 4 and 8 are the semi-minor axes. The minor axis is the length of the minimum dimension of the galaxy, and the semi-minor axis is half that length

Columns 5 and 8 are the semi-major axes. The major axis is the length of the maximum dimension of the galaxy, and the semi-major axis is half that length

Columns 6 and 9 are the eccentricities, calculated by the standard equation

The King cluster model affects the galaxy in a lesser manner due to its larger core radius. Not as much mass is within the distance from the galaxy center to the cluster center for the King model as compared to the lens model. Hence, there is not as much gravitational influence from the King model compared to the lens model. Cluster-to-disk mass ratios also play a role in the morphology changes of the galaxy. With a larger mass ratio, one notices a drastic difference in the change of the major and minor axes for each of the runs. The galaxy becomes far more elliptical with an increase in the cluster-to-disk mass ratio for the lens model. For a cluster-to-disk mass ratio of 1000, at a distance of 150kpc, the eccentricity is 0.27 for the lens model, and 0.51 for the King model. For a cluster-to-disk mass ratio of 10000 at the same distance, the lens model eccentricity is 0.57, and 0.52 for the King model. Note the lesser change in the eccentricity for the King model, while at the same time there a doubling in the eccentricity for the lens model.

With the higher mass ratio, the galaxy follows its orbit at a faster rate. The cluster is more massive than the galaxy and the force of attraction it has on the galaxy becomes much greater, drawing it in at a faster rate. Because of the this, the galaxy is under the influence of the cluster for a shorter period of time, and the tidal effects are less pronounced. For the King model with mass ratio of 1000, it takes 234×10^6 years for it to reach 100kpc from the center of the cluster, assuming a time step of 1×10^6 years. For the same King model with a mass ratio of 10000, it only takes 78×10^6 years. This time difference can be noted in the difference of shape between the two simulations. On the other hand, with a mass ratio of 10, it takes the galaxy over 1×10^9 years to reach 100kpc from the cluster center, regardless of the mass model. Contrary to increasing the cluster-to-disk mass ratio, increasing the number of particles did not change the time it took for the galaxy to reach the center of the cluster. With the assumption of 1×10^6 years per time step, the galaxy took the same amount of time to reach the center for both the 100000 particle case and the 60000 particle case for a mass ratio of 100000.

The data shows that star formation also increases as the cluster-to-disk mass ratio increases. For a ratio of 10000, star formation began at 150kpc from the cluster center. In the time to go from 150kpc to 4.15kpc, 350 stars were formed from 897 collisions, giving an efficiency of 19.5% and a formation rate of 14 stars/10^6 years. For a ratio of 100000, formation began at 184kpc, and, in the time to go from there to 37kpc, 404 stars formed from 569 collisions, giving an efficiency of 35.5% and a formation rate of 36 stars/10^6 years. Each of these simulations was done with 60000 particles and a 0.2 gas-to-total particle ratio. If one increases the mass ratio, there are fewer collisions, but more stars form, increasing the efficiency of the collisions to form collapsed clouds. Table 2 summarizes this data:

fmass	f_gas	particles	stars	collisions	efficiency	time steps	rate(per Myr)	cloud type
10000	0.2	60000	350	897	19.51%	24	14.58	HI
10000	0.3	60000	738	2033	18.15%	24	30.75	HI
100000	0.2	60000	404	569	35.50%	11	36.73	HI
100000	0.2	100000	992	1474	33.65%	12	82.67	HI
100000	0.3	60000	840	1245	33.73%	13	64.62	HI
10000	0.2	60000	4088	13657	14.97%	88	46.45	GMC
10000	0.3	60000	7140	27339	13.06%	88	81.14	GMC
100000	0.2	60000	2642	4603	28.70%	27	97.85	GMC
100000	0.2	100000	5712	11649	24.52%	27	211.56	GMC
100000	0.3	60000	4934	9506	25.95%	27	182.74	GMC

Table 2

Column 1 is the cluster-to-disk mass ratio
Column 2 is the gas-to-total particle ratio
Column 3 is the total number of particles used
Column 4 is the number of clouds that collapsed from the onset of star formation until the end of the simulation. The collapsed clouds are assumed to form stars.
Column 5 is the number of collisions that occurred from the onset of star formation until the end of the simulation
Column 6 is the efficiency of the process, calculated by dividing the number of clouds collapsed by twice the number of collisions, which is the possible number of collapsed clouds.
Column 7 is the number of time steps during which star formation occurred
Column 8 is the formation rate per 1×10^6 years
Column 9 is the type of gas cloud used in that run

From the data, a definite increase in the predicted star formation rate occurs for a disk galaxy under the influence of a cluster. For the Milky Way, our own galaxy, the rate is about 1 solar mass per year. The mass of the neutral hydrogen clouds is assumed to be 280 solar masses. For the run with cluster-to-disk mass ratio of 10000 and gas-to-total particle ratio of 0.2, the rate is 0.03 solar masses per year. For the analogous run for GMCs, which have a range of masses, extending from 1×10^5 solar masses up to 1×10^6 solar masses, the rate is 4.6 solar masses per year.

A change in the gas fraction, all other parameters the same, led to a change in the efficiency and formation rate. An increase in the gas fraction for the run with mass ratio of 10000 with 60000 particles led to a minimal decrease in the efficiency of the process, while also producing an increase in the formation rate by more than doubling the it, again assuming a 1×10^6 time step.

All of the previous results were taken from runs that used neutral hydrogen clouds as the gas component of the galaxy, with the lens model of the cluster. The use of giant molecular clouds leads to similar conclusions. Again note the runs in which the cluster-to-disk mass ratio was 10000 and the number of particles was 60000. Comparing the runs for gas-to-total particle ratios of 0.2 and 0.3, there was a minimal decrease in the efficiency of the process for the 0.3 run compared to the 0.2 run, while the doubling of the rate was again seen. However, one can see where the conclusions for the neutral hydrogen runs do not hold for similar runs for GMCs. For GMCs, as one increases the mass ratio, there is not an increase in stars formed, but rather a decrease in the number of stars formed, along with a decrease in collisions. This decrease in star formation paired with the decrease in collisions led to a higher efficiency for the run with cluster-to-disk mass ratio of 100000 than for the run with a ratio 10000, while the doubling of the formation rate is still evident.

IV. CONCLUSIONS

The data on the morphology and the star formation rates leads to many different conclusions about the effect of the cluster mass distribution on the morphology and star formation rate for a disk galaxy on a radial orbit of the cluster.

An increase in the mass of the perturbing cluster leads to an increase in the star formation rate for a disk galaxy. This is due to the tidal effects of the cluster and the change in velocity imparted to the orbiting gas clouds in the disk. The gravitational lens cluster model, which is typical of the epoch of galaxy evolution, z=0.2, produces an increase in the star formation rate of a disk galaxy on a radial orbit in comparison to an unperturbed galaxy. At the z=0.2 epoch, sub-clusters within the cluster are merging and forming a greater mass. A factor of 10 increase in the mass ratio produced an order of 2 increase in the star formation rate.

An increase in the number of particles used in the simulation does not necessarily lead to changes in efficiency of the process, nor does it lead to changes in the star formation rate.

A change in the model used for the mass distribution of the cluster produces a noticeable change in the shape of the galaxy. The King model does not distort the shape of the galaxy as much as the model derived from gravitational lensing does. An increase in the cluster-to-disk mass ratio also leads to a lesser change in the shape of the galaxy. An isolated galaxy keeps its circular shape throughout the simulation. A cluster-to-disk mass ratio of 10 is too small to produce gross tidal effects in the shape of the galaxy, while ratios of 1000,10000, and 100000 all produce noticeable effects. However, for the simulations that have the cluster-to-disk mass ratios of 10000 and 100000, the galaxy follows its orbit at a faster rate so that the tidal effects are not as pronounced as in the simulations where the cluster-to-disk mass ratio was 1000. Also, the galaxy is under the influence of the galaxy for less time than the run with cluster-to-disk mass ratio of 1000. Thus, an initial change in shape is noted, while no change in shape is seen after that because it is falling in at a faster rate.

Much future work can be done in this area of galaxy evolution. More realistic models for the collapse of the gas clouds could be included, along with other types of cluster mass distributions. The effect of supernova remnants on star formation and the effect of the newly formed stars should also be included to make the simulation more realistic. The number of stars formed from a gas cloud is another important factor to be considered. The masses of the clouds are much greater than the mass of the sun, so many stars could possibly form from the collapse of a single cloud. The types of stars formed when a gas cloud collapses is also very important consideration. If the stars formed go quickly to supernova status, this will also change the star formation environment. Energy from the supernovae can enhance the star formation or increase the temperature of the gas to a point where it is more resistant to gravitational collapse. The initial mass function (IMF) of the newly formed stars needs to be put in to take into account the type of star formed. Experimental data needs to be compared to the predictions of the model. The shape of the galaxy at a certain radius will be key is determining the validity of the current simulations.

REFERENCES

1. Henriksen, Mark J. and Byrd, Gene. "Tidal Triggering of Star Formation by the Galaxy Cluster Potential." The Astrophysical Journal, vol. 459, pp. 82-88.
2. Sarazin, Craig. "X-ray Emission from Clusters of Galaxies." Rev. Mod. Phys., vol. 58, January 1986, p. 77.
3. Binney, James and Tremaine, Scott. Galactic Dynamics, Princeton University Press, Princeton, NJ, 1987, p. 363.
4. Henriksen, Byrd. ibid.

/

SIMPLE SCALING IN GALAXIES AND DARK MATTER

Richard T. Hammond*
North Dakota State University
Physics Department
Fargo, North Dakota 58105 U.S.A.

Kwan-Wu Lai
Mail Stop 301-150
Jet Propulsion Lab
California Institute of Technology
Pasadena, CA 91109-8099

Rebecca K. Sundhagen
Physics Department
North Dakota State University
(February 21, 1997)

One of the outstanding unresolved problems in physics is the dynamics of spiral galaxies. In particular, we are left with the following choice: Either matter in the outer regions of these galaxies fails to obey Newton's (and therefore Einstein's) laws, or the galaxy is composed primarily of invisible, or dark, matter. Either of these solutions has associated problems, and this article will discuss the situation as it stands today, and offer a classification scheme.
(*) e-mail rhammond@plains.nodak.edu

I. INTRODUCTION

Spiral galaxies are generally made up of three components: The central bulge or spheroidal component, the disk, and the halo. The bulge is characterized by older stars that have an intensity profile which may be described by $I = I_0 \exp\{-kr^{1/4}\}$. The stars in this region are not in uniform motion about any point, and the bulge for many spirals may be small or negligible. The disk region is characterized by an intensity profile of the form $I = I_0 \exp\{-r/r_d\}$ where length r_d is typically between 1 and 5 kpc. A useful measure of the optical size of the galaxy is the Holmberg radius, which corresponds to a radius at which the intensity is 25.6 mag arcsec^{-2}, which is between one and two percent of the background brightness. Since the 1970's, there has been a steady increase in the number of measurements made beyond the Holmberg radius. In this region, the most notable measurements come from the 21 cm radiation of neutral hydrogen. Measurements far beyond the Holmberg radius have shown that the hydrogen is in orbit around the galaxy, and that *the velocity is independent of the radius*. This was unexpected because, in this region, most of the mass of the galaxy is contained within the visible portion of the galaxy, and therefore, from Newton's law, one has $v^2 = GM/r$ where M is the mass of the galaxy. Thus, one expects the rotation curve (v vs. r) to show a $1/\sqrt{r}$ dependence for large r, but it does not. Instead, the rotation curves are flat or nearly flat, and virtually none shows the "expected" $1/\sqrt{r}$ form. These flat (or nearly flat) rotation curves have led to the assumption of a 'dark halo.' Dark matter is assumed to act gravitationally like any other matter, but remain invisible by direct measurement. For example, if one assumes that there is dark matter which may be described by a density $r_{dark} = C/r^2$ in the outer portion of the galaxy, then the application of Newton's law for circular orbits shows that v = constant. In order to avoid the singularity at the origin, one also uses a form $r_{dark} = C/(r + a)^2$ where a is a constant. With a = 0, the mass density is that of an isothermal sphere, although in the literature either of these forms is sometimes referred to as the isothermal sphere. Details about galactic structure can be found in Binney and Tremaine.[1]

Thus, the introduction of dark matter solves the flat rotation curve problem, but raises new questions, like "what is dark matter?" There is an intense theoretical effort underway to answer this question, so the reader is referred to the literature.[2] There are two other important aspects of dark matter. One is that the total amount of dark matter is typically between 1 and 10 times the observed mass of the galaxy. Thus the majority of the mass of the universe may be invisible to us. The other point is that the mere existence of dark matter is not enough: It must also yield flat rotation curves. In other words, the density of dark matter has to be adjusted so that flat rotation curves result. In all cases, the dark matter has a different distribution than that of the visible matter, and a scale length larger than that of the ordinary matter. Because of this, the dark matter is believed to form a halo around the galaxy. Thus, the amount and distribution of dark matter must balance against the visible matter in just the right proportion in order to yield a flat rotation curve. This effect is sometimes referred to as the disk-halo conspiracy.

The past two decades have harbored a continually burgeoning observational and theoretical interest in this subject. In the following, an introduction to the literature is presented.

II. LIGHT ON DARK MATTER

The existence of dark matter had been postulated long ago,[3] but the use of dark matter to account for flat rotation curves was first postulated by Freeman in 1970,[4] and since that there has been considerable observational evidence of flat rotation curves.[5] By the 1980's, the reality of dark matter in spiral galaxies seems to have been adopted by most astronomers, and attention turned to more specific and detailed properties of the dark matter and rotation curves.

Although the use of dark matter has provided explanations for all observed rotation curves, there is not universal acceptance of its existence. For one thing, there is little direct evidence of its existence. Recent evidence for the existence of massive compact halo objects (MACHOs) comes from the microlensing effect.[6] More recent work indicates that the halo consists of other objects in addition to MACHOs.[7] The next problem is that the mere existence of dark matter does not explain why the rotation curves are flat. A further assumption relating to its distribution must also be made (the disk-halo conspiracy). In fact, in all cases, the dark matter must have a scale length much greater than the visible matter. This is unsettling because it is also assumed that, from a gravitational view, dark matter behaves no differently than the visible matter. If so, then why does dark matter have a different distribution? Another nagging question is this: If the vast majority of the universe is made of dark matter, and we develop all our physical laws on visible matter, then what are the chances that we have the correct Laws of Nature when they are derived by viewing a small and special kind of matter? Finally, the laws of physics, especially those of gravitation, have been subjected to independent tests only on the scale of our solar system or smaller. At galactic distances and greater, we may be seeing the beginning of the breakdown of our theories. This thought has opened the door to alternative or modified theories of gravity.

When researchers present data to show the existence of dark matter and to refute alternate gravity theories, they sometimes start off with the phrase "we would like to dispense with the *ad hoc* modifications to the theory of gravity" while those supporting alternate gravity counter with "we would like to dispense with the ad hoc introduction of invisible matter." The first modern theory that was specifically concocted to account for the rotation curves without dark matter is the Milgrom hypothesis, which is often referred to as MOND (MOdified Newtonian Dynamics).[8] This approach generalizes the equation $F = ma$ to $F = (x)ma$ where $x = a/a_o$ where a is the acceleration and a_o is the critical parameter. Here, (x) is an adjustable function that goes to unity for large x and to x for small x. This was put on a firmer theoretical foundation by Bekenstein.[9] Later, for a sample 10 galaxies, Begeman et. al. conclude that MOND gives the best fit to the rotation curves— as good as the three-parameter dark halo models, but more efficient (in that there are less free parameters).[10] However, recent evidence challenges this result. In 1986 Sanders considered the use of a modified potential (but keeping $F = ma$) by generalizing the Newtonian potential to a Yukawa potential.[11] He found that rotation curves could be matched by using a repulsive finite range vector force, from which the name FLAG (Finite Length Anti-Gravity) was suggested. Sanders later conceded that FLAG cannot account for all of the rotation curves.[12] Dubal et. al.[13] also argued that neither FLAG nor a logarithmic potential term introduced by Kuhn and Kruglyak[14] can account for the rotation curves. However, in 1993 Eckhardt used two Yukawa potentials, one attractive and one repulsive, to account for the observed rotation curves.[15] One argument sometimes put forward against alternate gravity theories is the unnatural invention of extra forces. However, a theory of gravity that predicts an attractive and repulsive finite range force, with the correct equations of motion, had already been proposed.[16] In this work, however, attention was focused on the gauge invarient case, in which the bosons acquire zero mass. In a separate development, there has been a long standing interest in conformally invarient gravitational theory. In the higher derivative theory of Mannheim and Kazanis, a constant potential is predicted from the equations of motion.[17] The resulting quark-like force can also account for the rotation curves of spiral galaxies.

The above shows that there are many possible explanations of the rotation curves of spiral galaxies, but there are more! Battaner et. al. argue that galactic magnetic fields can account for the rotation curves.[18] They show that a partially ionized gas in a 6μG magnetic field would give the required forces to produce a (nearly) flat rotation curve. Persic and Salucci counter with the argument that this effect fails for galaxy pairs.[19]

As a final note, we realize that the actual dynamics may include several of the above phenomena, such as dark matter and a modified gravitational theory. One may also conclude that the rotation curve of any galaxy can be very well described by any one of many approaches, as the above literature attests to. For this reason, we attempt to quantify overall trends or scaling behavior of galaxies. In the following, it is assumed that Newtonian gravity holds, and the origin of the flat rotation curves arises from the existence of dark matter.

III. COMMON CURVES

Typical rotation curves are shown in Fig 1. Fig. 1a is the most famous, or well known, rotation curve for NGC 3198. Galactic rotation curves of this shape will be referred to as *flat*.

Fig. 1b shows another common shape and is referred to as *rising*, and finally Fig. 1c displays another common shape which will be called *dipped*.

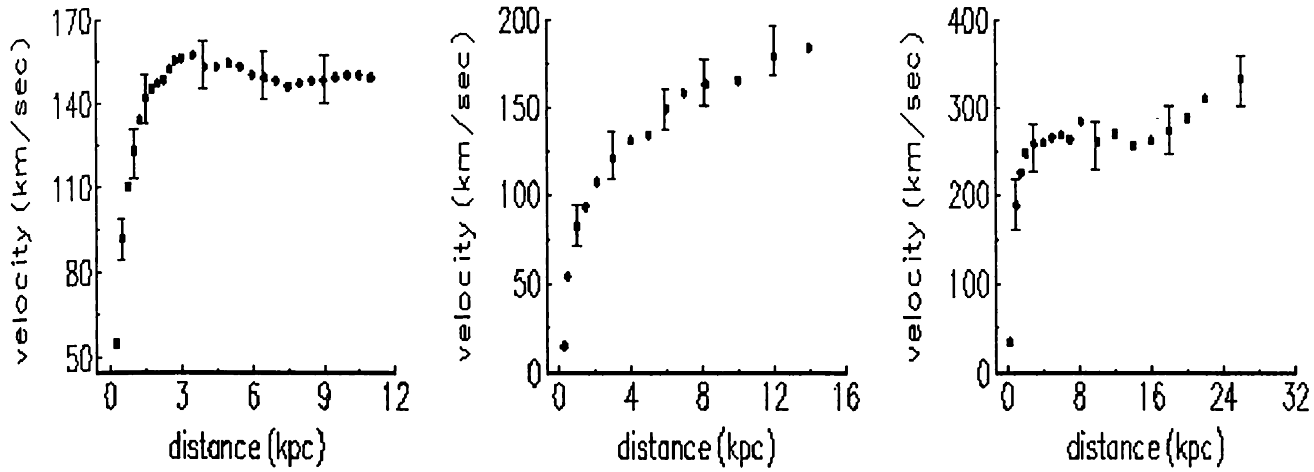


Figure 1a, 1b and 1c. The velocity vs. distance for flat, rising, and dipped galaxies.

It has been demonstrated that any of these shapes can be fit by theoretical models. The origin of these shapes arises from the relative density scales of the two different types of matter. In the 'rising' category, the density scales are closest, whereas in the flat curves the dark matter density is, essentially, further away from the galactic center. The 'dipped' galaxies represent the case where the dark matter is furthest out. In this view, the downward part of the dip is understood as the beginning of the Keplerian fall off, and then as the distance increases, the region of dark matter is entered, producing the rise.

There are various distributions of dark matter that can give rise to a single shape. Thus, a single galactic rotation curve is not enough to specify the distribution of dark matter. Worse, it is also possible to fit rotation curves without dark matter at all, but instead with an alternate gravitational theory, as described above. To make matters even more nebulous, different alternate theories can also yield the same galactic rotation curve.

For these reasons it seems useful to look for common features of many rotation curves taken together. Instead of trying to fit a theory or mass distribution to a single galaxy, we look for common features to all galaxies. With this mind, we show some simple scaling behavior in the following figures. The galaxies used in the following plots are: For the flat galaxies, G1085, G2815, G3054, G3145, G3198, G4800, G7083, G7171, G7537, N3672, U11810, U12810. For the rising galaxies, G1325, G1620, G2708, G3223, N1035, N2742, N4062, N4605, N4682. For the dipped galaxies, G1417, G3200, N1421, N2715, G7606, N7664. The data for galaxies is taken from Rubin et. al.[20]

To exhibit the scaling, Fig. 2 represents a graph for each type using the galaxies named above. Each galaxy is assigned an numerical factor, α, chosen so that the graphs match. In particular, for the given galaxy the velocity at each distance is multiplied by α. Each galaxy is assigned its own α, but only one α per galaxy. Typical values range from $\alpha = 0{:}5$ to $\alpha = 2$. The fact that a single parameter can be used to make two different galaxies look the same, which is shown in these figures, is not obvious from theoretical grounds. For example, in many galactic rotation curves, there are three parameters used to make the data match the theory. The fact that a single α factor can make different galaxies match seems to point to some underlying universal phenomenon.

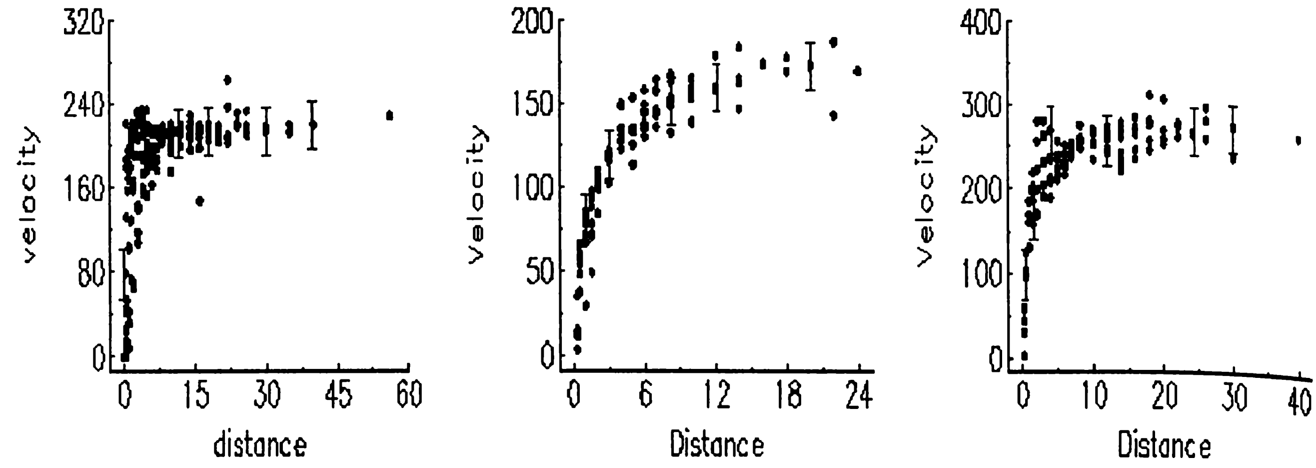


Figure 2. Alpha normalized rotation curves for flat, rising, and dipped galaxies.

The simple scaling behavior may be viewed as another version of the disk-halo conspiracy. There is no reason 'a priori' that this scaling should hold. If the underlying reason is dark matter, then this scaling is a reflection of the fact that the dark matter distribution has a different scale length than visible matter, and that the maximum rotational velocities, obtained from either the visible matter alone or the dark matter alone, are about equal. If the explanation lies in an alternate theory of gravity, then this implies that there is a scale parameter in the theory that is of galactic dimension.

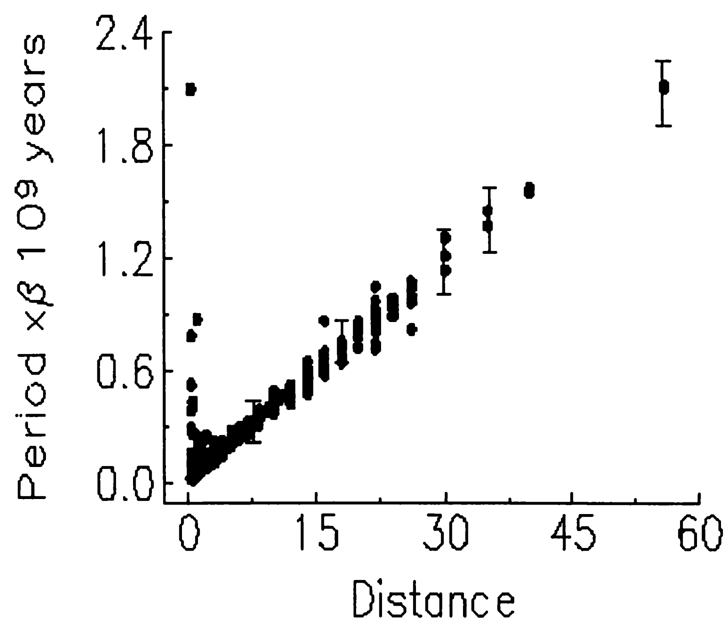


Figure 3. Period vs. radius with b factor for 27 galaxies.

In the above, the α factor was chosen by eye to make the curves match. A less subjective means can be achieved by considering the period curves. The period of a star in a circular orbit is $T = 2\pi r/v$. Because v is nearly constant over most of the region, it is seen that this equation will yield a straight line. The deviations from the straight line occur principally for small r.

In Fig. 3, these curves are made for those used in Fig. 2a. The quantity T / β is plotted against r and now β is chosen so that all the graphs have the same slope. Thus, the β factor is roughly the same as the α factor, but now there is a more objective way to choose it.

IV. SUMMARY

Although dark matter is the favored explanation for the shape of the rotation curve, there is also theoretical evidence that these rotation curves really point to an alternate, or modified theory of gravity. The correct solution of the rotation curve conundrum may invoke both dark matter and alternate gravity. In order to classify some of the known information about rotation curves, we developed three categories which are called, rising, dipped, and flat. It is also shown that, within these categories the rotation curves differ by an overall scaling factor, α, which is pictured in Fig. 2. A more objective way to obtain the scaling factor is developed which considers the period *vs.* distance. This method is shown in Fig. 3.

The scaling factor we have emphasized is a quantitative means of comparing many different galaxies within a given class (flat, rising, or dipped). Any individual rotation curve can be adequately described by a judicious choice of parameters for dark matter, and most can be so described by a good scale choice in alternate gravity theories. The challenge is no longer to explain em how the rotation curves are flat— the challenge is to explain *why* they are flat. Neither the dark matter invocation nor the alternate gravity approach offers much explanation. The scaling equivalence described above may shed new light on a dark problem

ACKNOWLEDGMENTS

This research was funded by a NASA grant NAG8-1007. R.T.H. would like to thank the kind hospitality he received from the Jet Propulsion Lab, during his stay there.

REFERENCES

[1] J. Binney and S. Tremaine, *Galactic Dynamics* (Princeton University Press, Princeton, 1987).
[2] *Particle Physics and Cosmology: Dark Matter*, (Current Physics Sources and Comments, Vol. 6, Edited by M. Srednicki, North Holland, 1990)
[3] *Modern Cosmology and the Dark Matter Problem* (D. W. Sciama, Cambridge University Press, 1993).
[4] K. C. Freeman Ap. J. **161**, 802 (1970).
[5] C. Alcock et. al., Phys. Rev. Lett. **15**, 2867 (1995).
[6] E. I. Gates, G. Gyuk, and M. S. Turner, Phys. Rev. Lett. **19**, 3724 (1995).
[7] S. M. Faber and J. S. Gallager, Ann. Rev. Astron. Astrophys., **17**, 135 (1979). V. C. Rubin, W. K. Ford, and N. Thonnard, Astrophys. J. bf 238, 471 1980; V. C. Rubin, W. K. Ford, N. Thounnard, and D. Burstein, Astrophys. J., bf 261, 439 1982.
[8] M. Milgrom, Astrophys. J., **270**, 356; 371 (1983).
[9] J. Bekenstein and M. Milgrom, Astrophys. J., **286**, 505 (1977).
[10] K. G. Begeman, A. H. Broils, and R. H. Sanders, Mon. Not. astr. Soc., **249**, 523 (1991).
[11] R. H. Sanders, Astron. Astrophys., **154**, 135 (1986).
[12] R. H. Sanders, Mon. Not. astr. Soc., **223**, 539 (1986).
[13] M. R. Dubal, P. Salucci, and M. Persic, Astron. Astrophys., **227**, 33 (1990).
[14] J. R. Kuhn and L. Kruglyak, Astrophys. J., **313**, 1 (1987).
[15] D. H. Eckhardt, Phys. Rev. D, **48**, 3762 (1993).
[16] R. Hammond Gen. Rel. Grav. **23**, 973 (1991).
[17] P. D. Mannheim and D. Kazanas, Gen. Rel. Grav. **26**, 337 (1994).
[18] E. Battaner, J. L. Garrido, M. Membrado, and E. Florido, Nat. (Lett.) **360**, 652 (1992).
[19] M. Persic and Salucci, Mon. Not. R. Astron. Soc., **261**, L21 (1993).
[20] V. R. Rubin, D. Burstein, W. K. Ford, Jr., and N. Thonnard, Astrophys. J., **289**, 81 (1985).

THE NORTH DAKOTA SPACE GRANT PROGRAM AND ASTRONOMICAL RESEARCH AT THE DEPARTMENT OF SPACE STUDIES, UNIVERSITY OF NORTH DAKOTA

Steven H. Williams
Department of Space Studies
University of North Dakota

I. Introduction

The Department of Space Studies at the University of North Dakota administers the North Dakota part of the national Space Grant Program for the benefit of all citizens of the state. Educational materials distribution, scholarships and fellowships, grants for educational activities, and other support of (science) education are all part of our mission. Two of the initiatives started by the NDSGP that are using astronomical research capabilities to advance student learning are the focus of this presentation: the creation of the Planetary Science Observatory (Figure 1) and SPACE.EDU, a new and innovative way for distance students to take a Masters program in Space Studies from their homes. Both are undergoing an ongoing development, at least in part with Space Grant support, and offer both significant improvements in short-term educational delivery and, more importantly, we plan to combine them so that their joined capabilities exceed their sum calculated separately.

II. The Planetary Science Observatory (PSO)

The UND Department of Space Studies presently operates a NGT 18" Newtonian telescope (Figure 2) in a domed observatory near Emarado, ND, about 14 miles from campus. A SBIG ST-6 CCD camera is used for imaging. The light gathering and recording power of the CCD potentially allows students to conduct meaningful research on projects that are significant, yet are too numerous to attract the attention of limited professional astronomy research. A few students have conducted individual research projects as part of their Space Studies curriculum, using the telescope to derive asteroid light curves (hence, rotation rates), light curves of variable stars, and search for extragalactic supernovae, and all students are greatly attracted by the prospect of being able to acquire and process images that have an impressive visual impact (Figure 3). Space Grant funding also allowed the author to participate in a NSF-funded program (Research Techniques for Undergraduate Faculty for Small Observatories; administered by Harvard's Center for Astrophysics) specifically designed to provide instruction on how to incorporate astronomical observations made by CCD-equipped students into undergraduate astronomical curricula.

III. SPACE.EDU

SPACE.EDU was established a year ago to provide a mechanism for the non-traditional student to obtain a Masters degree in Space Studies remotely; only a short summertime visit to the UND campus is required. This mode of education delivery is ideally suited to our unique program (the only one like it in the United States) and to our unique body of distance students, most of whom are presently employed as military officers or in some professional capacity in a space-related industry. Our program allows them to advance their educations without unduly burdening either professional or family life. Our typical student is older than the average campus student, and brings to the learning environment a mature perspective and level of professional experience. Our younger students benefit greatly from their exposure to such student cohorts, and the quality of instruction, both on and off-campus, has increased accordingly. We now have ~180 distance students and have become the largest graduate department on campus.

The method of instructional delivery for the typical SPACE.EDU class combines the use of videotaped lectures (campus classes are taped in a professional studio the semester prior to offering the class on SPACE.EDU), textbook and related materials, and an interactive weekly chat session on the Internet. The latter feature is essential to the quality of our program. The distance student is exposed to most everything a campus student sees and does in the classroom, uses the same text, and, in addition, takes part in instructor-led group discussions. Exams are taken and homework, papers, etc. are collected on-line. Feedback from the students, both in their written comments and in the form of continuously-increasing enrollment, has been overwhelmingly positive. Partly as a consequence of establishing SPACE.EDU, the Department of Space Studies won the McDermott award from the UND Foundation for Departmental Excellence in Teaching in February, 1996.

Most of the classes offered on campus are presently offered via SPACE.EDU or will be in the near future. We are also exploring new partnerships with NASA centers to provide educational seminars on the kinds of specialized expertise only available at those centers that is in big demand with our students. This term, we were able to offer an 8-week seminar on Telerobotics from the NASA Ames Research Center in California. By the end of the term, each student was able to control a prototype Mars roving vehicle from their computers at home. Eighty students, many of them new to our program, enrolled in this first seminar, and we are aggressively pursuing additional collaborations with NASA centers in the future. We have already been contacted by potential employers eager to discuss job opportunities with our students taking our program in general and these seminars specifically.

IV. Growth Issues

The PSO can be a useful tool for student education, but its utility is limited by several factors. First, the weather in North Dakota makes astronomical observation difficult or impossible much of the year. Second, the equipment is difficult to use to the point that student frustration becomes significant. Third, there is no way at present to incorporate the use of the telescope in distance learning classes. Space Grant funds are presently being expended to upgrade the facility to overcome those difficulties.

The adverse effect of the local climate on observing cannot be eliminated, but improvements are underway. The high latitude of the observing site is a problem; it leads to very harsh winter conditions under which the dome, slit, and telescope hardware have a difficult time functioning properly. In the Summer, sunsets are late, sunrises early, and the Sun never gets more than ~20° below the northern horizon. New observing equipment will not improve the weather, but we are presently losing some nights of potential observations because of the marginality of the weather and the remoteness of the observing site.

The NGT telescope was designed to deliver big aperture at relatively modest cost. As a consequence, the mounting and drive of the scope are less advanced in design and construction than those of a more expensive instrument. Target acquisition with the very narrow field of view of the ST-6 camera is a big problem. Although the mounting is equipped with electronic setting circles, their accuracy is less than the CCD field. The recent addition of a flip mirror (a device that allows placing an eyepiece or the CCD in the light path as desired) has alleviated this problem somewhat. In any case, the weather, the remoteness of the observatory, and difficulties in using the equipment all conspire to reduce student willingness to use it. Further, nothing about the present equipment allows its use by a distance student. The Department, therefore, has two needs: in the short-term it would be nice to have a upgraded, more user-friendly telescope and imaging system and in the long-run, a telescope that is capable of fully remote operation, one that could be controlled by a distance student using the Internet as a communication medium, is desirable.

V. Upgrades Underway

The Department of Space Studies has recently purchased a Meade LX-200 16" telescope and has arranged for a new shelter structure to be built adjacent to the present observatory site. The telescope has been delivered and the main portion of the shelter structure has been erected at the time of writing; final construction and installation awaits the arrival of Spring. The LX-200 should meet our short-term needs right away. Its pointing accuracy is sufficient to capture the desired object in the CCD field first-time, every time. The simplified roll-off shelter roof will allow greater ease of operation in cold weather; the present dome and slit often are affected by cold and drifting snow to the point they cannot operate, an inconvenience and even dangerous on cold nights. The more-advanced model CCD that will be used with the new instrument has a built-in provision for autoguiding that will make noise-free long exposures possible. The present telescope will continue to be heavily used for teaching and public outreach functions, but the new telescope will shoulder the departmental research activities.

The more exciting prospect offered by the equipment upgrade is that the LX-200 is amenable to remotely controlled operation. Couple with that capability a remote control operation of the shelter roof and CCD camera, and you have equipment capable of supporting our long range goal of providing a legitimate astronomical research opportunity to our distance learning student. Our goal is for any of our students to be able to control the telescope (when it is their turn!) from anywhere on Earth and to be able to download and process the resulting data, all from their desks at home or anywhere. We feel that such equipment would be both a powerful educational tool and would significantly expand our research opportunities and capabilities.

We are encouraging our students to be prepared for research opportunities with the new equipment that could lead to student publication of results. We are specifically going to be involved in the study of the light curves of eclipsing binaries and other variable stars, continue the investigation of asteroid light curves, and embark on a systematic attempt to discover new asteroids, both Main Belt and Near Earth. If there is sufficient student interest, we will also conduct a standing patrol for extragalactic supernovae. Another benefit of the planned upgrade is that it provides an opportunity for innovative research that is difficult to anticipate ahead of time, therefore, we fully expect the new equipment capability to inspire our students to think of ways of using it in research avenues at present unanticipated.

More information about our unique academic program, our collaborations with NASA center on seminars, and about our observatory facility can be obtained from our department homepage (http://www.space.edu).

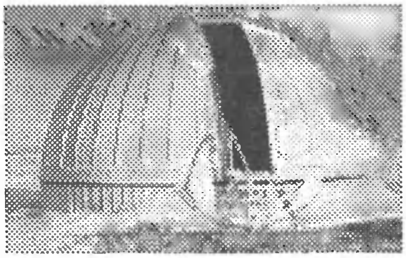


Figure 1. The UND Department of Space Studies' Planetary Science Observatory near Emerado, ND, was built using a silo top converted into an observatory dome. The dome offers adequate protection for the telescope, but the dome and slit are difficult to manipulate in cold weather.

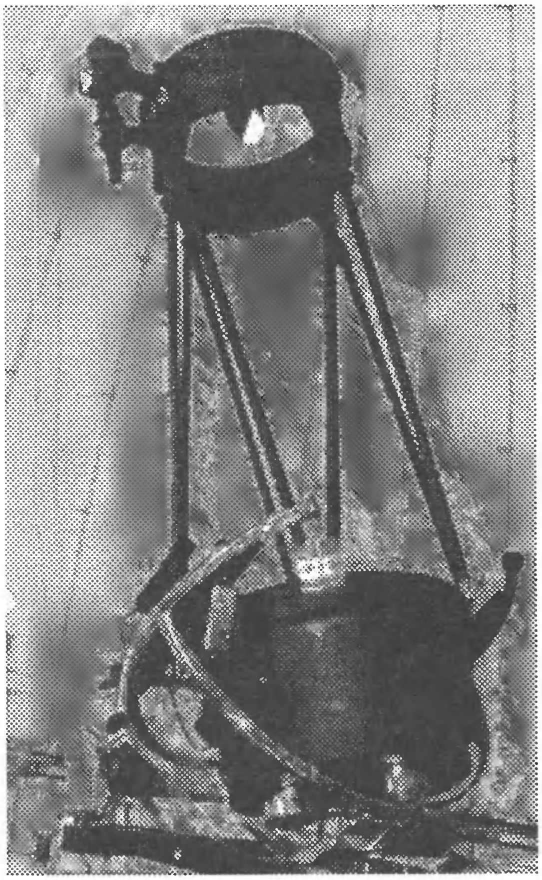


Figure 2. The NGT 18" Newtonian reflector and CCD (upper left corner) camera used at the PSO. The secondary mirror is readily visible.

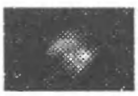


Figure 3. A thumbnail view of M27, the dumbbell Nebula in Vulpecula, acquired by a student using the PSO equipment. Many students are impressed and stimulated by their newfound ability to acquire and process attractive astronomical images.

SYMPOSIUM: TECHNICAL ASPECTS OF COAL COMBUSTION BY-PRODUCTS COMMERCIAL UTILIZATION

COAL COMBUSTION BY-PRODUCT (CCB) USE IN NORTH DAKOTA

Oscar E. Manz*
Manz Associates, RR 1 Box 30, Alvarado, MN 56710

PROCESSING AND UTILIZATION OF WET FLUE GAS DESULFURIZATION MATERIAL

Andrew Stewart* and David J. Hassett
Cooperative Power Association, 14615 Lone Oak Road, Eden Prairie, MN 55344
Energy & Environmental Research Center, University of North Dakota, Grand Forks 58202

USE OF COAL COMBUSTION BY-PRODUCTS FOR SOLIDIFICATION/STABILIZATION OF HAZARDOUS WASTES

David J. Hassett* and Debra F. Pflughoeft-Hassett
Energy & Environmental Research Center, University of North Dakota, Grand Forks, ND 58202

UTILIZATION OF NORTH DAKOTA LIGNITE COMBUSTION BY-PRODUCTS IN ROAD-BUILDING APPLICATIONS

Bruce A. Dockter* and Debra F. Pflughoeft-Hassett
Energy & Environmental Research Center, University of North Dakota, PO Box 9018 Grand Forks, ND 58202-9018
Andrew Stewart
Cooperative Power Association, 14615 Lone Oak Road, Eden Prairie, MN 55344-2287

COAL COMBUSTION BY-PRODUCT (CCB) USE IN NORTH DAKOTA

Oscar E. Manz*
Manz Associates, RR 1 Box 30, Alvarado, MN 56710

keywords: high-volume fly ash concrete, flowable mixtures, roadbed stabilization, mineral wool

INTRODUCTION

The author is a professor emeritus in civil engineering from the University of North Dakota, where he taught from 1953 to 1989. He performed extensive testing and research for over 25 years, involving mainly lignite coal ash in portland cement concrete, roadbed stabilization, flowable mixtures, mineral wool, ceramic products, and sulfur concrete. Much of the research involved actual in-the-field studies. The work reported in this paper consists of high-volume fly ash concrete, flowable mixtures, and roadbed stabilization.

UTILIZATION OF FLY ASH IN ROADBED STABILIZATION

In contrast with pozzolanic bituminous fly ashes, the western American lignite and subbituminous fly ashes are both pozzolanic and cementitious. By "western" fly ash, we mean ash produced from combustion of low-rank western coals mined in North Dakota, Wyoming, and Montana.

The pozzolanic properties of fly ash, which enable it to react with lime to form cementitious products, have made fly ash a good-quality base or subbase course material when used with lime or cement to stabilize aggregates and soils, or when used alone with lime or cement. Construction procedures utilize standard equipment and techniques for central mixing or mix-in-place operations.

The American Society for Testing and Materials (ASTM) has developed a specification for the use of fly ash with lime in lime–fly ash–soil aggregate mixtures (1). This specification (ASTM C593 – Fly Ash and Other Pozzolans for Use with Lime) establishes minimum unconfined compressive strength and durability requirements for mixtures using coarse-grained soil. These requirements are often specified for projects where lime and fly ash are used to stabilize fine-grained soils. The unconfined compressive strength criterion of 400 psi (2760 kPa) in 7 days under accelerated curing conditions has proven to be quire acceptable, except that recommendations have been made for reducing this requirement to as low as 100 psi (690 kPa) for subbase applications (2). In this procedure, a sample is held in vacuum for a specified time and then soaked. The unconfined compressive strength at the end of this test has been shown to correlate very well with the strength of samples which have been subjected to five or ten cycles of the freezing–thawing (but not brushed). The criterion specified for the strength at the end of the test has been suggested as 400 psi (2760 kPa), which allows for essentially no loss of compressive strength between the start and the end of the durability test. The advantage of the vacuum saturation test is that it can be performed in about an hour, whereas the standard durability test requires about 24 days to perform.

Road-building applications of lignite fly ash in North Dakota have resulted in the largest tonnage utilized to date. Poz-o-pac road base mixtures, composed of ¾-inch maximum aggregate, fly ash, and lime have been used for several years in the eastern half of the United States. In 1971, the first lignite fly ash–lime–aggregate base (poz-o-pac) was placed in North Dakota near the site of the Basin Electric power plant, a few miles south of Stanton. Approximately 13% fly ash and 2% hydrated lime were mixed with 85% aggregate and sufficient water to obtain maximum density.

So far, this paper has only dealt with fly ash, but a stabilized mine haul road study was conducted for the lignite mine adjacent to the Coal Creek power plant, which also has bottom ash available. In addition to Coal Creek fly ash and bottom ash, three mine spoil materials and a pit-run gravel were used in this study to explore possible mixes suitable for mine haul road construction. The use of 100% Coal Creek fly ash produced an unusually high vacuum saturation strength of 1780 psi. A mix with 25% fly ash, 37.5% bottom ash, and 37.5% pit-run gravel is equivalent to 100% fly ash.

In another test, the three ashes from the Beulah, North Dakota, site (gasification ash, scrubber ash, and bottom/economizer ash) were used in the weight proportion in which they are generated at the Beulah plants. The test results exceeded the 400 psi requirement for the vacuum saturation test.

Conclusions

Because of variations in chemical and physical properties, not all western fly ashes perform alike for stabilization.

Since there are marked differences in the gradation and clay content of the various existing gravel–clay roads, it is important to perform ASTM C593 vacuum saturation tests with varying amounts of fly ash and lime.

The moisture contents and mixing and curing sequences are very important when performing stabilization studies.

HIGH-VOLUME FLY ASH CONCRETE

In 1988, the North Dakota Mining and Mineral Resources Research Institute received a grant from the Electric Power Research Institute to study the construction and potential environmental implications of high-volume low-rank coal fly ash utilization. The project was carried out at the Coal Creek Station, located near Falkirk, North Dakota.

The objective of the project was to demonstrate the use of low-rank coal fly ash as a high-volume replacement (70%) for portland cement in concrete and in controlled density flowable fill (CDFF) and to investigate any environmental effects that might result from these high-volume fly ash applications. To meet these objectives, the project design included four major tasks: 1) Background Monitoring, which consisted primarily of physical, chemical, and leaching characterization of the fly ash; 2) Construction Monitoring, which included quality control monitoring of the fly ash during construction and monitoring of concrete placement; 3) Environmental Monitoring of surface runoff, moisture in the saturated and unsaturated zone, and groundwater by strategic placement of water quality monitoring instruments and leaching characterization of produced concrete and fill material; and 4) Postconstruction/Performance Monitoring for a period of 2 years following placement of the concrete and fill.

Site preparation and concrete placement are discussed in detail elsewhere (3, 4), including mix designs, construction procedures, and construction monitoring information too lengthy to be included in this publication. The concrete was batch-mixed off-site and transported to the Coal Creek Station. Standard paving techniques were generally employed. During the construction phase, the fly ash was monitored using ASTM tests.

During the summers of 1988 and 1989, approximately 25,000 square yards of 8-inch-thick concrete pavement, containing 1042 tons of fly ash, were poured at the Coal Creek Station for this project. The areas paved included several parking lots and access roads at the station. During construction, a testing program was carried out to evaluate the physical properties of the high-cement replacement concrete. In addition to the paving work, several sections of pipe culvert were backfilled with CDFF.

A quality control program was performed during the construction phase of the project to monitor the concrete and CDFF placement activities. The following information was collected for the quality control program:

- Daily concrete pour data, including slump, air content, unit weight, pour volume, and sample collection information
- Subgrade compaction measurements
- Concrete aggregate gradation
- Concrete unconfined compressive strength
- Concrete sulfate resistance
- Concrete freeze–thaw resistance
- Daily fly ash CDFF pour data
- Fly ash CDFF unconfined compressive strength

With a few exceptions, applicable specifications were met throughout the construction phase.

The slurry was designed to flow readily by gravity around the pipe culvert. The strength of the cured slurry was in the range of 150 psi, which is high enough to support traffic but not so strong that it would be difficult to remove if the pipe should need repairs. The slurry was mixed and transported to the Coal Creek Station in ready-mix trucks.

The cubic yard mix consisted of 250 lb of Coal Creek fly ash, 25 lb of portland cement, 3000 lb of fine aggregate, and sufficient water for required flow characteristics.

Background leachate evaluation of the Coal Creek fly ash was also performed prior to the construction phase of this project. The EPA EP-toxicity leaching procedure, which was the specified regulatory leaching procedure at the time of this project, and the ASTM leaching test procedure (D3987) were used to evaluate the leaching potential of the Coal Creek fly ash. Leachates were analyzed for an extensive list of parameters, including those designated by the Resource Conservation and Recovery Act (RCRA) (arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver), cationic and anionic species important to the understanding of mineralization of natural water (aluminum, calcium, iron, magnesium, potassium, silicon, sodium, and sulfate), and other trace elements of interest (copper, manganese, molybdenum, and zinc). Results of the leachate analyses were compared to the RCRA maximum contaminant levels (MCL) and primary drinking water standards. The results of leachates generated using these two procedures on two composite fly ash samples, published in the interim report (3), indicate that the Coal Creek fly ash leaches very low amounts of the elements analyzed.

Conclusions

The low-rank coal fly ash used in this research project leached only very low concentrations of trace elements in laboratory leaching protocols and is considered nonhazardous according to regulatory standards set by RCRA. Analyses of leachates and runoff collected at the demonstration site also showed low concentrations of trace elements.

The performance of the concrete placed in this demonstration project has been satisfactory. Initial evaluation of this demonstration has been very positive, and even in areas of heavy traffic, the concrete has shown only very limited engineering faults.

MINERAL WOOL

Mineral wool is a fibrous product made from melted rock, glass, and slag for use as building, pipe, and sound insulation. In the United States, the industry dates from 1870 when a plant, using slag as the principal raw material, was established in Greenfield, New Jersey (5).

One of the most important parameters for slags in the production of mineral wool is the so-called acid/base ratio (6). This has a great effect on the viscosity of the material. In general, the acid/base ratio is defined as the sum of the oxides, such as SiO_2, P_2O_5, Al_2O_3, and TiO_2, which form anion complexes in melts (silicates, phosphates, aluminates, titanates) divided by the sum of oxides, such as CaO, MgO, Fe_2O_3, and MnO, which destroy the anion complexes in melts (network modifiers). The ratio may be calculated on weight or a molar basis. Optimum acid/base ratios for producing good mineral wool have been determined chiefly on an empirical basis and, ideally, should be near one. On a weight basis, a ratio ranging from 0.8 to 1.2 appears optimum.

Processes for producing mineral wool are basically simple, but there can be many variations. However, processes attempt to accomplish the following objectives:

- Melt the feed charge
- Fiberize the molten stream
- Manufacture various mineral wool products

The mineral insulation industry uses two main methods of fiberization: a) spinning and b) blowing, but details of the methods and the equipment design are considered by the individual companies to be confidential. Both methods produce some shot, which is a small amount of bead material at the end of the formed fiber.

Spinning

The many variations of the spinning technique, such as horizontal, vertical, and cup types, are all based on the centrifugal principle. The technique may use flat plates or disks placed horizontally or spinning wheels in a single or multiple configuration. The wheel is dish-shaped and generally water-cooled. The wheel is concave in cross section and faced with special metals to minimize wear and erosion.

The molten stream falls onto or into the spinner which, revolving at high speed, causes the melt droplets formed to be thrown out at high speed, elongating the molten slag particle into a cometlike tail with a shot or bead attached. Much of the shot is removed before the fiber product is formed. It is easily understood that proper operation, including speed of the wheels, could have an influence on the physical properties of the fiber, e.g., length and diameter.

Blowing of the Molten Liquid

In this technique, the molten stream is allowed to fall from the furnace and, at a proper distance from it, is subjected to a blast or jet of high-pressure air at right angles. The liquid forms small droplets which are propelled through the air. The droplets are elongated, with a shot adhering to the end of the fiber. Most commonly, the gas used in blowing is pressurized air, but steam is also used. Industry has shown that no deleterious effects were experienced in switching from steam to air. Air pressures can vary from 50 to 200 psi. Various nozzles are used or have been proposed for blowing mineral wool. Their design should allow a high gas velocity to first break up the slag droplets and then direct the molten stream into a higher gas velocity to elongate the particle. After fiberization, the mineral wool is collected in a chamber or cyclone for further processing. The equipment in this processing line is dependent on the type of product being produced.

Manufacturing Mineral Wool from Power Plant Slag

Many power plants throughout the world utilize what is known as wet-bottomed boilers to produce steam to generate electric power. Two types of by-product material are created by this type of boiler. By design, fly ash makes up approximately 30% to 40% of the residual material produced by wet-bottomed boilers. The second type of by-product is what is called slag or bottom ash. Inside the boiler itself, crushed coal is fed in at high velocity and combusted. The molten slag falls to the bottom of the boiler and collects in a pool. The pool of molten slag, at a temperature of approximately 2606°F, is drawn off through an opening in the bottom of the boiler. At this point, the slag drops approximately 10 feet into water. As the slag is quenched, it shatters like glass and is slurried out of the power plant for disposal.

In the North Dakota area, four power plants utilize wet bottom boilers: the Milton R. Young Station at Center, North Dakota; Coyote Station at Beulah, North Dakota; Leland Olds Station at Stanton, North Dakota, and Big Stone Station at Big Stone, South Dakota. It was found that the Coyote and Big Stone plants had sufficient room in the boiler area to potentially add the equipment necessary to fiberize mineral wool (7). The type of equipment that would be installed at any particular power plant would vary, depending upon the type of product desired. The main component of fiberization at a power plant would be a means of deflecting the stream of molten slag to a fiberization device.

Preliminary fiberization tests using Coyote slag as the raw material resulted in a mineral wool product that had an acceptable average fiber diameter of 5.5 mm but which had a high shot content of approximately 65%. In defense of the high shot content, again it should be stressed that the samples were produced in a nonoptimized, unsteady-state experimental environment (8).

Conclusion

This preliminary work leads to the selection of the Coyote power plant as the most promising site for manufacturing mineral wool.

References

1. American Society for Testing and Materials (1983) "Standard Specifications for Fly Ash and Other Pozzolans for Use with Lime—Procedure C 593-76a," 1983 Annual Book of ASTM Standards, Vol. 04.02.

2. Dempsey, B.J. and Thompson, M.R. (1973) "Vacuum Saturation Method for Predicting Freeze–Thaw Durability of Stabilized Materials," Record No. 442, Highway Research Board, pp 44–57.

3. Moretti, C.J. and Manz, O.E. (1990) "Demonstration of Ash Utilization in the State of North Dakota," Interim construction completion report.

4. Stewart, A. (1991) "Utilization of Low-Rank Coal Fly Ash in High Applications at a North Dakota Power Station," Draft proceedings of the Sixteenth Biennial Low-Rank Fuels Symposium, May 20–23, 1991.

5. Robertson, R.H.S. "Rock Wool as an Industrial Raw Material," Chem Ind. 12, 482.

6. Swanson, Michael (1985) Economic Evaluation of Manufacturing Mineral Wool Insulation from Power Plant Slag.

7. Manz, O.E. and Eaton, L.C. (1982) Production of Mineral Wool from Lignite Coal Slag, March.

8. Manz, E.O. (1980) "Utilization of Coal By-Products from Western Coal Combustion in the Manufacture of Mineral Wool and Other Ceramic Materials," Cement and Concrete Research 14, 513–520.

PROCESSING AND UTILIZATION OF WET FLUE GAS DESULFURIZATION MATERIAL

Andrew Stewart* and David J. Hassett
Cooperative Power Association, 14615 Lone Oak Road, Eden Prairie, MN 55344
Energy & Environmental Research Center, University of North Dakota, Grand Forks 58202

BACKGROUND

Flue Gas Desulfurization

Utility emissions of sulfur dioxide are controlled by a variety of methods, including the following systems:

- Wet scrubbers
- Spray dry scrubbers
- Sorbent injection
- Regenerable processes
- Combined SO_X/NO_X processes

Flue gas desulfurization (FGD) systems may be classified into two broad types: nonregenerable and regenerable. In systems using the nonregenerable process, the SO_2 remains permanently bound with the sorbent to form a new compound. In the systems using the regenerable process, the SO_2 sorbent can be reused following the regeneration step that produces liquid SO_2, sulfuric acid, or elemental sulfur. Figures reported by the American Coal Ash Association (ACAA) indicate that nearly 20 million tons of FGD material was produced in the United States in 1995, but only approximately 7% of this material was utilized.

Wet Scrubbers

Processes that produce wet products are often described as wet scrubbers. These systems commonly use limestone, slaked lime, or a mixture of slaked lime and alkaline fly ash as sorbents. The sorbent is sprayed into the flue gases where it reacts with the SO_2 to form an insoluble calcium compound. The residues from these processes are generally calcium sulfite, or calcium sulfate if forced oxidation has been employed. The wet scrubber materials are generally thixotropic, thus difficult to dewater, and have specific handling and disposal requirements.

Spray Dry Scrubbers

In spray dry scrubbers, a solution or slurry of alkaline material is mixed with the flue gases at air preheater outlet temperatures. The flue gases are humidified by finely dispersed droplets. The water is evaporated, salts are precipitated, and the remaining solids are dried, generally to less than a few percent of free moisture. The precipitated solids and fly ash are entrained in the flue gas and carried away from the spray dryer to a particulate collection device. Slaked lime is commonly used as a sorbent, resulting in an end product consisting of a mixture of calcium sulfite/sulfate and fly ash.

Sorbent Injection

In sorbent injection systems, a dry calcium- or sodium-based sorbent is either added to the coal or injected into the boiler or duct work. Sorbents used include limestone, lime, and trona or nahcolite. Hybrid systems have been developed that use more than one sorbent and/or injection points. Sorbent injection systems produce a dry calcium or sodium sulfite/sulfate waste mixed with the fly ash.

Other Processes

An alternative approach to dry flue gas cleaning involves the use of a circulating fluidized-bed absorber or gas suspension and absorption unit. These systems use a reactor vessel in which a pulverized dry sorbent, such as sodium bicarbonate, limestone, lime, or calcium hydroxide, comes into contact with the SO_2-laden flue gases in a fluidized bed or other reactor vessel. A solid-gas separator, located downstream of the reactor, concentrates unused sorbent for recycle and subsequent reuse for additional SO_2 capture.

Typical Utilization Scenarios for FGD Material

The residues from wet and dry FGD systems have similar chemical properties. Major constituents are calcium sulfite, calcium sulfate, fly ash, and excess reagent. These properties are significantly different from pulverized coal combustion fly ash and can be best utilized following processing. Calcium sulfite, generally the major component of FGD material, is typically oxidized to calcium sulfate, which with water forms gypsum. This is usually separated and dewatered for utilization. The purity of the FGD gypsum residues from the wet limestone/gypsum systems typically range from 95%–99%. Optimization of the FGD process can ensure a by-product with a consistent quality suitable to substitute for natural gypsum in a variety of applications. Typical utilization applications for FGD gypsum include agricultural applications, a feedstock for cement production, and manufacture of gypsum wallboard. In most cases, the purity of gypsum necessary for these applications requires the removal of fly ash before the scrubbing process to avoid contamination of the gypsum with fly ash.

COOPERATIVE POWER'S COMMITMENT TO ENVIRONMENTALLY SOUND UTILIZATION OF BY-PRODUCTS

Cooperative Power's Coal Creek Station (CCS) became fully operational in 1981. The two 550-MW units at CCS burn North Dakota lignite. The resulting by-products are fly ash, bottom ash, and wet FGD material. Although disposal of the coal combustion by-products (CCBs) was included in the original site plan at CCS, even early on, consideration was given to utilization of the fly ash as a mineral admixture for concrete and as a partial sorbent replacement for the wet scrubbing system. CCS fly ash has been successfully marketed into North Dakota, Minnesota, and the surrounding region as a construction material that is environmentally benign, highly consistent, and an excellent performer in numerous construction applications.

Attempts to use CCS fly ash as part of the scrubbing medium in the wet scrubbing system at the site were not as successful as first hoped, primarily due to the abrasive nature of the fly ash. Currently, CCS scrubbers use lime as the scrubbing medium for SO_2 removal.

CCS's efforts to market its fly ash have been successful, so with increased awareness of the economic advantages of by-product utilization, the favorable U.S. Environmental Protection Agency (EPA) regulatory determination that CCBs are not hazardous, and the improved understanding of potential local and regional markets, Cooperative Power has taken additional steps to investigate the processing and utilization of its wet FGD material.

LABORATORY- AND PILOT-SCALE PROCESSING OF CCS WET FGD MATERIAL

Samples of CCS wet FGD material were collected and evaluated. Typical samples were approximately 15%–20% solids content, exhibited thixotropic behavior, and were primarily calcium sulfite and calcium hydroxide. The pH of the original samples was approximately 7.0–7.5. Samples that were stored at room temperature generated H_2S after several weeks, indicating reduction of sulfur under anaerobic conditions.

The laboratory equipment used for oxidation experiments consisted of a 3-necked, round-bottom flask fitted with a paddle stirrer. Air was introduced into the flask through glass frit at the bottom of the flask, and the pH was controlled through addition of dilute sulfuric acid. Samples were removed and the sulfite content was determined at regular intervals. When the sulfite content was not detectable, the oxidation was considered complete. The sample was then allowed to settle and was filtered, washed, and air-dried. The oxidized material was then analyzed to determine the mineral composition. It is important to note that as the oxidation approached completion the physical nature of the sample changed from a thixotropic substance to a two-phase (liquid–solid) material, and the solid phase readily settled out of solution. This was an additional visual indication of the oxidation process.

Two laboratory-scale oxidation trials were performed on the FGD material. These were performed at pH 5 and pH 4. The first experiment, at pH 5, required 10 hours to completely oxidize the calcium sulfite to calcium sulfate. The second experiment, at pH 4, achieved complete oxidation in 6 hours. The resulting solid samples of oxidized FGD material were air-dried and evaluated using x-ray diffraction which verified that the material was approximately 98%–99% pure gypsum.

The next phase of the work involved a scaleup to a pilot-scale oxidation process to oxidize four 55-gallon drums of the FGD material. The pilot-scale process was performed at pH 4 in a stainless steel reaction vessel. Automatic pH control was used to maintain the pH of 4 with sulfuric acid. The other laboratory-scale requirements of stirring and introduction of excess air were replicated in the pilot-scale experiment. The pilot-scale experiment proceeded at a slower rate than the laboratory-scale experiment, requiring 80 hours to achieve completion. The final sample was separated and air-dried, yielding 675 pounds of air-dried product. Analysis of the air-dried product indicated that the material was again 98%–99% pure gypsum.

MARKET OPPORTUNITIES FOR FGD GYPSUM

As stated earlier, there are several key utilization applications for FGD gypsum. These include agricultural soil amendment, feedstock for cement manufacture, and production of gypsum wallboard. It has been proposed that the use of FGD gypsum as an agricultural soil amendment may be highly advantageous for treatment of sodic soils. The need to have the soil amendment in the form of gypsum or calcium sulfate is that the calcium sulfate is more soluble than the calcium sulfite in nonoxidized FGD material. As can be determined by the process used to achieve oxidation, the oxidation of calcium sulfite to calcium sulfate is not easily achieved, so it is advantageous for effective soil amendment to oxidize the FGD material before using it in this application. It is also much easier to handle with conventional equipment as gypsum, which can be granulated or pelletized for application, rather than the thixotropic FGD material that is generated in the scrubbing process. One advantage of this market is that the product consistency can usually exhibit greater variability in agricultural applications than in industrial applications. Agricultural soil amendment applications will likely be seasonal, so material storage may be a requirement and needs to be considered. Generally, the agricultural applications for CCBs are high-volume applications, but the market price for these materials is also generally lower than industrial applications.

The use of FGD gypsum in cement and gypsum wallboard manufacturing has become more common in recent years as these industries become more aware of the advantages of recycling and the costs of raw virgin materials. In these applications, the purity and consistency of the FGD gypsum are critical. Another key issue with supplying FGD gypsum to these industries is transportation. If transportation costs from the FGD gypsum production site to the manufacturing site are too great, especially relative to other natural or by-product sources, it will be difficult to market the FGD gypsum into these industries. All of these issues need to be evaluated as part of the marketing and economic evaluation of processing FGD material as a management strategy.

OPTIONS FOR COMMERCIAL-SCALE OXIDATION OF FGD MATERIAL

The oxidation process used for the laboratory- and pilot-scale experiments summarized in this document was performed using an ex situ process. The wet FGD material was removed from the scrubbing system after the SO_2 had been reacted with the scrubbing medium. This process can be scaled up to commercial scale as one option; however, there are also options that are generally referred to as in situ oxidation processes. In these processes, the oxidation of the calcium sulfite is forced simultaneously during the scrubbing process. For both the ex situ and in situ processes, there are commercial systems available that can be retrofitted onto existing scrubbers at utility sites. Each system offers advantages either in purity of the FGD gypsum that can be produced or in cost-effectiveness based on the amount of handling and added materials to achieve the oxidation. It is beyond the scope of this paper to evaluate the advantages and disadvantages of all the commercially available systems; however, it is important for individual companies to perform cost-benefit analyses of the various options, taking into account the FGD gypsum markets of highest interest.

Additional considerations that have been alluded to for commercial-scale oxidation processes include the potential need for granulation, pelletizing, or other postprocessing to facilitate handling, storage, or shipping. Short- and long-term storage considerations must also be evaluated for some utilization applications such as agricultural soil amendment. Quality assurance testing should also be considered as part of the marketing needs, and an alternate plan for management of the FGD material should be considered for cases when specifications may not be met because of process failure or inconsistency.

CONCLUSIONS

FGD material is only one by-product of coal combustion at CCS, but the preliminary work presented here is indicative of some general CCB management issues. CCBs are high-volume materials that can perform well in numerous applications when management plans include the needed options for utilization. A good CCB management plan can benefit from a well- thought-out marketing plan. The laboratory- and pilot-scale work described in this document provided the background information showing that a high-quality FGD gypsum can be produced from CCS FGD material. Cooperative Power continues to evaluate the economics of commercial-scale oxidation of CCS FGD material and the market potential for CCS FGD gypsum.

USE OF COAL COMBUSTION BY-PRODUCTS FOR SOLIDIFICATION/STABILIZATION OF HAZARDOUS WASTES

David J. Hassett* and Debra F. Pflughoeft-Hassett
Energy & Environmental Research Center, University of North Dakota, Grand Forks, ND 58202

INTRODUCTION

The coal combustion by-product (CCB) industry has been interested in the utilization of CCBs for waste solidification/stabilization for several years. Previous research performed at the Energy & Environmental Research Center (EERC) and cofunded by the U.S. Department of Energy (DOE) and Gas Research Institute (GRI) identified an important stabilization mechanism for elements that exist as oxyanions in aqueous solutions, including arsenic, boron, chromium, molybdenum, selenium, and vanadium. This mechanism is the formation of the mineral ettringite, which has been shown to incorporate oxyanionic species into its structure during the formation process. This mineral was identified in comingled by-products from coal combustion and gasification. Follow-on research at the EERC has focused on ettringite synthesis from laboratory reagents and the determination of potential mechanisms of stabilization through ettringite formation. In numerous unrelated CCB research projects funded by DOE and/or industry, ettringite has been identified as a hydration product in a variety of alkaline CCBs. Reduction in the mobility of several trace elements is commonly noted with the presence of this mineral in hydrated CCBs. The cementitious and pozzolanic properties of coal combustion fly ash that make it useful in concrete also allow it to solidify and chemically immobilize soluble inorganic wastes and organic chemicals. Significant interest exists in using fly ash and clean coal technology by-products for waste stabilization, and several commercial vendors have developed patented processes. Commercial waste stabilization processes typically involve controlled mixing and curing using lime, fly ash, portland cement, and various additives.

The discovery that ettringite formation could be used to remove potentially hazardous oxyanions from solution was made during an EERC research project involving the disposal of coal gasification solid and liquid wastes (1). It was observed that solution concentrations of some potentially toxic trace elements decreased with time during long-term leaching in certain mixtures. At the same time, characterization of solids in the wastes showed the concentration of the mineral ettringite was increasing over time. This observation was a major advancement in waste treatment technology and led to additional research on ettringite. Ettringite is a mineral with the nominal composition $Ca_6Al_2(SO_4)_3(OH)_{12} \cdot 26H_2O$. Ettringite is also the family name for a series of related compounds, known as a mineral group or family, which includes the following minerals (1):

Ettringite	$Ca_6Al_2(SO_4)_3(OH)_{12} \cdot 26H_2O$
Charlesite	$Ca_6(Si,Al)_2(SO_4)_2(B[OH]_4)(OH)_{12} \cdot 26H_2O$
Sturmanite	$Ca_6Fe_2(SO_4)_2(B[OH]_4)(OH)_{12} \cdot 26H_2O$
Thaumasite	$Ca_6Si_2(SO_4)_2(CO_3)_2(OH)_{12} \cdot 24H_2O$
Jouravskite	$Ca_6Mn_2(SO_4)_2(CO_3)_2(OH)_{12} \cdot 24H_2O$
Bentorite	$Ca_6(Cr,Al)_2(SO_4)_3(OH)_{12} \cdot 26H_2O$

There are two technical approaches to the use of ettringite formation for the fixation and removal of trace elements from solution. One approach is the formation of a minimal amount of ettringite in a very large volume of solution to remove trace concentrations of elements such as boron and selenium. An alternate approach using ettringite formation is to solidify the entire mass, thus incorporating the oxyanionic elements of interest into the ettringite structure as a monolith. This approach is more applicable for the treatment of smaller volumes of solutions containing high concentrations of boron and/or selenium, accomplishing two objectives: first, the waste is solidified, and second, the hazardous components of the liquid waste are chemically incorporated into the solid matrix. If the procedure is properly performed, a solid with high compressive strength is produced, incorporating excess alkaline components. This process has the potential to produce a highly stabilized mass for the disposal of high-concentration liquids containing boron, selenium, or any other element capable of substituting into the ettringite structure.

EXPERIMENTAL

Five low-rank coal combustion fly ash samples extensively characterized in previous projects (2) were used as a pool of candidate materials for potential use as waste stabilization agents. Two of these fly ash samples were selected because ettringite formed in the solid in long-term leaching experiments, and an associated reduction in leachate concentration of at least one trace element was noted for each sample. Stabilization experiments were performed using these two samples.

The stabilization experiments were designed to evaluate the removal of relatively high concentrations of boron and selenium from a simulated wastewater. The boron and selenium concentrations were determined from samples of contaminated water from a proprietary source. Sulfate was added as one variable in order to determine if high concentrations of sulfate would impact the ability of the ettringite to include trace elements in its structure. The experiments were carried out in 2-liter containers with a 20-to-1 liquid-to-solid ratio (similar to leaching protocols) and continuous end-over-end agitation over the 60-day duration of the experiment. The stabilization experiments were performed using the following matrix:

TABLE 1

Matrix of Experimental Variables

Starting Concentration	Simulated Wastewater A, mg/L	Simulated Wastewater B, mg/L
B	15	15
Se	0.1	0.1
SO	0	500

Samples of the liquid phase from each experiment were collected at regular time intervals through the 60 days of the experiment. The rotator was stopped, and after the bulk of the solids had settled, samples were collected using a syringe. The samples were then filtered through a 0.45- m filter, acidified with concentrated ultrapure nitric acid to 5%, and stored at 4°C in Teflon bottles until submitted for analysis. The boron concentrations were determined by inductively coupled argon plasma (ICAP) spectrometry, and the selenium concentrations were determined with heated graphite furnace atomic absorption spectrometry (HGA–AAS). A time–concentration comparison was developed as shown in the following section.

RESULTS AND DISCUSSION

All results of the analyses of the liquid samples for the stabilization experiments are presented in Tables 2 and 3. The presence of ettringite in the reacted solids was confirmed by x-ray diffraction.

The two sets of data for each sample indicated similar results for changes in boron and selenium concentrations. Set A for each material used a simulated wastewater with boron and selenium only. Set B for each material used a simulated wastewater with boron, selenium, and sulfate. The starting concentrations of all simulated wastewater components are noted above. The analyses of the liquid samples indicated two different phenomena: 1) an increase in solution concentration of boron and selenium; and 2) solution concentration reduction of boron and selenium approaching 100%.

Results for Ash 2 indicated no reduction in boron or selenium concentrations with time, as was expected. In fact, a slight increase in boron and selenium concentrations over the concentrations in the simulated wastewater was noted. These increases may be a result of additional analyte being leached from the solid sample into the liquid phase, or they may be an artifact of the analytical technique used. Quality control methods included in the analyses indicated that the results are accurate; however, it cannot be confirmed that additional analyte was leached from the solid without additional analysis, which was beyond the scope of this study.

TABLE 2

Analytical Results – Solution Concentrations for Simulated Wastewater Treated with Ash 1

	B, mg/L	% B Reduction	Se, mg/L	% Se Reduction
Solution A				
6 hours	7.87	47.5	0.045	55.0
12 hours	6.01	59.9	0.034	66.0
18 hours	4.54	69.7	0.025	75.0
24 hours (1 day)	3.81	74.6	0.025	75.0
2 days	1.60	89.3	—	—
3 days	0.69	95.4	—	—
4 days	0.44	97.1	—	—
5 days	0.39	94.4	—	—
6 days	0.42	97.2	—	—
7 days (1 week)	0.34	97.7	<0.02	>80
4 weeks	0.30	98.0	0.023	77.0
8 weeks	0.24	98.4	0.021	79.0
Solution B				
18 hours	5.09	66.1	0.025	75.0
7 days (1 week)	0.38	97.5	<0.02	>80.0
4 weeks	0.40	97.3	0.023	77.0
8 weeks	0.20	98.7	0.020	80.0

TABLE 3

Analytical Results – Solution Concentrations for Simulated Wastewater Treated with Ash 2

	B, mg/L	% B Reduction	Se, mg/L	% Se Reduction
Solution A				
18 hours	18.0	-20.0	0.11	-10.0
7 days (1 week)	17.8	-18.6	0.12	-12.0
4 weeks	16.7	-11.3	0.106	-6.0
8 weeks	17.2	-14.7	0.13	-30.0
Solution B				
18 hours	18.3	-22.0	0.13	-30.0
7 days (1 week)	18.6	-24.0	0.12	-12.0
4 weeks	16.9	-12.7	0.105	-5.0
8 weeks	18.4	-22.7	0.13	-30.0

Analytical results of solution concentrations of boron and selenium for Ash 1 indicated a relatively quick and consistent reduction of both elements over time. The concentration reduction for boron was > 95 %, and the concentration reduction for selenium was > 75 %.

The primary question regarding the reported results from the stabilization experiments was why the two samples, both of which were identified as ettringite formers, had different effects on the boron and selenium concentrations in the simulated wastewater. A further review of the available results was performed, leading to the development of several hypotheses to explain the observed phenomena.

The Ash 2 was likely prehydrated before received for analysis, as evidenced by the presence of ettringite in the original sample. Although it appears that additional ettringite was formed over the duration of the stabilization experiments, this proposed prehydration of the material may have resulted in a different ettringite formation mechanism. It is proposed that the fast-forming ettringite was already formed at the beginning of the experiment and the needed elemental components may have been depleted from the solid material. The leachate pH of Ash 2 was only slightly higher than the required 11.5.

In the course of other research performed at the EERC, it was noted that another compound, commonly referred to as monophase ($Ca_4Al_2[SO_4]_x[CO_3]_{1-x}[OH]_{12}\cdot 5\text{–}8H_2O$), appears to be equally important in waste treatment. Monophase is a phase related to ettringite by its common components, Ca, Al, SO_4, OH, and H_2O, as well as its similar synthesis. It is hypothesized that the formation of monophase and potentially other mechanisms for, or precursors to, ettringite formation may have an impact on the ability of the ettringite formed to sorb other elements such as boron and selenium. The available information is not adequate to evaluate this hypothesis. An analytically intensive laboratory research project could be designed to evaluate ettringite formation mechanisms on the uptake of trace elements and facilitate the development of criteria for identification of CCBs that are the best candidates for use in waste stabilization.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn from the information obtained in this research:

- CCBs can be useful in the chemical fixation of potentially hazardous trace elements.
- Indication of ettringite formation alone is not adequate for selecting a CCB for waste stabilization applications.
- Moderate sulfate concentrations do not promote or inhibit trace element sorption.
- Ettringite formation mechanisms may impact trace element fixation and need to be elucidated.
- Laboratory demonstration of the CCB with the stabilization process being proposed for demonstration or commercial use is necessary to verify the efficacy of the material and process.
- The final waste form must be evaluated prior to management according to the required regulatory procedures.

REFERENCES

1. Hassett, D.J., Pflughoeft-Hassett, D.F. and McCarthy, G.J. Proc 9th Intl Ash Use Symp, Vol. 2: Stabilization and Aquatic Uses; Orlando, FL, Jan. 22–25, 1991, EPRI GS-7162, Project 3176, 1991.

2. Pflughoeft-Hassett, D.F., Dockter, B.A., Eylands, K.E. and Hassett, D.J. "Survey and Demonstration of Utilization Potential of North Dakota Lignite Ash Resources," EERC report 96-EERC-04-01 to the Industrial Commission of North Dakota, April 1996.

UTILIZATION OF NORTH DAKOTA LIGNITE COMBUSTION BY-PRODUCTS IN ROAD-BUILDING APPLICATIONS

Bruce A. Dockter* and Debra F. Pflughoeft-Hassett
Energy & Environmental Research Center
University of North Dakota, PO Box 9018 Grand Forks, ND 58202-9018

Andrew Stewart
Cooperative Power Association
14615 Lone Oak Road, Eden Prairie, MN 55344-2287

1.0 INTRODUCTION

Cooperative Power Association, the Industrial Commission of North Dakota, and the U.S. Department of Energy (DOE) provided funding for this research project at the Energy & Environmental Research Center (EERC) involving participation of the EERC's Coal Ash Resources Research Consortium (CARRC), Houston Engineering, Braun Intertec, Falkirk Mine, Manz Associates, the North Dakota Department of Transportation (NDDOT), the North Dakota State Health Department (NDSHD), and several additional North Dakota utilities. The laboratory information provided by the EERC through this project was originally intended specifically for use in the relocation of ND Highway 200 near Underwood, North Dakota, planned for initiation in 1995. Although this highway relocation project was postponed to 2009, the characterization and mix design information on concrete, controlled low-strength materials (CLSM), soil stabilization, and permeable base course presented in this report are applicable to general road-building projects and other public works and commercial projects following optimization of the mix designs.

This report discusses chemical, physical, and engineering characterization results from environmental and engineering perspectives, but will concentrate on the physical testing with an abbreviated presentation of the chemical analysis as it relates to leachate concentrations and RCRA limitations. Potential environmental impact is evaluated based on extensive chemical, mineralogical, and leaching characterizations developed with input from NDSHD. Available environmental data indicate that coal combustion by-products (CCBs) are not hazardous, as recognized by the August 2, 1993, ruling by the U.S. Environmental Protection Agency (EPA). This regulatory determination placed fly ash, bottom ash, boiler slag, and flue gas desulfurization materials under Subtitle D of the Resource Conservation and Recovery Act (RCRA), which delegates regulation of nonhazardous solid wastes to the individual states. The environmental information included in this report was designed to address specific concerns of the NDSHD relative to CCB utilization and disposal in North Dakota. The results indicate that the materials studied are nonhazardous. The physical and engineering characterization was used to develop mix designs for road-building applications of immediate interest to the engineering consultants responsible for the Highway 200 relocation project. The goal was to determine the appropriateness of various ND lignite combustion by-products for road-building applications.

2.0 BACKGROUND

In North Dakota, CCBs have varied characteristics based on several factors. One key variable is the coal source. In North Dakota, the coal utilized is North Dakota lignite (NDL). Other important variables in the production of by-products are primarily system-specific. These include coal handling; burner, boiler, and furnace types and configurations; by-product collection devices; emission control devices; and emission control reagents. The typical by-products formed from coal combustion processes include fly ash, bottom ash, boiler slag, and flue gas desulfurization (FGD) materials. Fluidized-bed combustion (FBC) materials are also available in North Dakota and elsewhere.

3.0 METHODOLOGY

Eleven lignite combustion by-product samples from six electric generating stations were submitted by four North Dakota utilities (Table 1). A broad variety of lignite combustion by-products are generated in North Dakota, however the scope of this project was limited to those most typical and of highest potential for use in road-building applications. The samples were selected with input from the NDSHD. The EERC requested samples from the utilities and provided them with sampling procedures to ensure representative samples.

TABLE 1

North Dakota Lignite Combustion By-Product Samples Evaluated

Utility Owner or Operator	Unit Name	By-Product Type FGD	FA[1]	BA[2]
Basin Electric Power Cooperative	Antelope Valley	X		X
	Leland Olds		X	X
Cooperative Power Association	Coal Creek Station		X	X
Minnkota Power Cooperative, Inc.	Milton R. Young		X	X
Montana–Dakota Utilities Co.	Coyote			X
	Heskett (FBC)		X	X

[1] Fly ash.
[2] Bottom ash.

3.1 Chemical and Environmental Characterization

The chemical and environmental characterization program for utilization and disposal included an evaluation of the leaching characteristics of the materials. Leaching characteristics are important for environmental and health reasons, both in disposal and utilization scenarios. The leaching characterization protocol developed at the EERC includes the use of both short- and long-term leaching procedures and a mineralogical evaluation of the leached material following long-term leaching. The leaching tests and leaching solutions for the synthetic groundwater leaching procedure (SGLP) and long-term leaching procedure (LTL) were selected on the basis of recommendations from the NDSHD. The short-term procedures were applied to the bottom ash and boiler slag samples. Short- and long-term leaching procedures were used for the fly ash and scrubber ash samples according to the recommendations of the NDSHD.

3.2 Development of Preliminary Mix Designs

The EERC developed preliminary mix designs based on the results of the characterization efforts. The mix designs were tailored to suit the utilization options identified by Cooperative Power, Houston Engineering, and Braun Intertec. The options are 1) concrete for a variety of pavement applications, 2) CLSM, 3) soil stabilization, and 4) permeable base course.

4.0 RESULTS AND DISCUSSION

4.1 Chemical and Leaching Characterization

The leaching results indicate that the leachates do not exceed RCRA limits for any RCRA elements and in most cases do not exceed primary drinking water standard limits. This is consistent with the regulatory determination by EPA that these materials are not hazardous wastes. It also indicates that these materials are excellent candidates for utilization in road building and other applications. Past projects investigating the utilization of Coal Creek Station fly ash for use in concrete pavement and CLSM have shown that the laboratory leaching results have indicated higher concentrations of some trace elements than were found in the associated field monitoring programs. The results of these demonstration projects indicate that laboratory leaching tests, designed to be relevant to the environmental situation for use or disposal, provide results indicative of field behavior.

4.2 Laboratory Testing of North Dakota Lignite Coal By-Products in Concrete, CLSM, Soil Stabilization, and Permeable Base Course

Currently across the state of North Dakota, fly ash used in concrete is obtained almost exclusively from the Coal Creek Station. Although other fly ash sources evaluated in this project such as Antelope Valley and Leland Olds indicate good potential for use in concrete based on results of empirical tests, these materials did not meet ASTM C618 specifications for use as cement admixtures. Because of the established precedent of using Coal Creek fly ash, which meets all ASTM C618 specifications, in this application, only this source is addressed here. The most recent research using Coal Creek fly ash in concrete (1,2) examined the physical effects of using fly ash for up to 70% replacement of cement. Depending of the level of fly ash usage and overall cementitious volume, the 28-day compressive strengths ranged from 2600 to over 4000 psi. Flexural strengths after 28 days of curing exceeded 800 psi. Extended curing times, up to 3 and 6 months, produced concrete compressive strengths of over 6000 psi. Based on compressive strength as the main design criterion, the optimum mix designs utilized from 30% to 40% replacement levels for fly ash for cement. When testing concrete containing fly ash for scaling resistance to deicing chemicals (ASTM C672), the ideal replacement level was 35%. At this level, the fly ash concrete performed as well as the control mixture, which contained no fly ash.

CLSM is a cementitious material, commonly a blend of cement, fly ash, sand, and water, that is usually flowable and self-leveling at the time of placement. It is generally used in nonstructural applications below grade where low strengths are desired. In these cases, the mature strength of the CLSM is intended to be no greater than that of the surrounding soils. American Concrete Institute (ACI) Committee 229 classes CLSM as a construction material having a maximum 28-day compressible strength lower than 1200 psi. If the mixture is intended to be removed at a possible later date, the design strength should actually be in the range of 30 to 150 psi. Uses of CLSM include backfill (sewer trenches, utility trenches, bridge abutments, conduit trenches, pile excavations, retaining walls), structural fill (foundation subbase, subfooting, floor slab base, pipe bending), and other miscellaneous uses (abandoned underground storage tanks, wells, abandoned utility company vaults, voids under pavement, sewers, manholes).

A CLSM mixture is designed so that all characteristics will have optimum conditions dependent on the application. Typically, the blends will be proportioned and the desired characteristics will be tested according to the appropriate standard procedures. The proper control of strength development in CLSM applications is probably the single most important criterion in developing the design mix. Not only must minimal strength development be met to provide structure support, but maximum strength development must usually be controlled also. Coal ashes need not meet ASTM C618 specifications for CLSM uses as long as the proper strength development is achieved. All fly ashes in this project were evaluated using the same mixture proportions. The quantity of cement used is probably higher than would normally be incorporated when cementitious ashes such as those produced from NDL are used. However, the mix design used was well established and is commonly referenced in numerous regions of the country. The mix proportions of the dry materials were the same for all ashes.

Soil stabilization is a tool for economical road building and roadway upgrading. Fly ash has been successfully used with granular and fine-grained materials to improve soil characteristics, thus providing adequate support for pavements, and to improve working conditions where undesirable soils are encountered. Stabilization of soil with fly ash alone has been rather limited in the United States. However, the availability of fly ash with a high free lime content, resulting from the burning of lignite and western coals, offers new possibilities on the stabilization field. A previous review of fly ash characterization has pointed out that the high-calcium (Class C) fly ash produced from western lignite and subbituminous coals has higher CaO, MgO, and SO_3 and lower Al_2O_3 and SiO_2 concentrations than fly ash from bituminous coal (3). The mineralogy of Class C fly ash can play an important role in its behavior as a cement replacement because the lime, when hydrated, can activate a self-pozzolanic behavior in the ash itself, and the two calcium phases can react with water in cementitious reactions. ASTM has developed a specification for the use of fly ash with lime in lime–fly ash–soil aggregate mixtures. This specification (ASTM C593, Fly Ash and Other Pozzolans for Use with Lime) establishes minimum unconfined compressive strength and durability requirements for mixtures using coarse-grained soil. The unconfined compressive strength criterion of 400 psi in 7 days under accelerated curing conditions has proved acceptable; however, recommendations have been made to reduce this requirement to as low as 100 psi for subbase applications (4).

The subsoils used were obtained from the Highway 200 relocation program and were provided by the Falkirk Mining Company in North Dakota. Samples were obtained from six locations along the proposed pavement site. The soil was first air-dried and then crushed to pass a No. 4 mesh sieve. The maximum dry density and optimum moisture content were determined according to ASTM D698, Test Methods for Moisture–Density Relations of Soils and Soil–Aggregate Mixtures Using 5.5-lb Rammer and 12-in. Drop. The maximum dry density and optimum moisture content are 100 pcf and 21.9%, respectively. After determination of optimum conditions, laboratory tests determined compressive strengths of the raw soil, soil and cement, and soil–fly ash–lime mixtures. Rather than determining optimum mix designs for all levels of fly ash, lime, and cement combinations, we used a standard level of mix proportions. An attempt was made to minimize the use of cement and maximize the use of fly ash and hydrated lime. Seven soil stabilization mixtures were evaluated. The only soil mixture containing cement utilized 15% soil replacement with cement. The remaining mixtures contained 12% fly ash and 3% hydrated lime. The test mixtures were compacted at a moisture content of within 2%–3% of the optimum moisture content of the in situ soil. Duplicate samples of each mixture were prepared for three separate durability procedures. One procedure cured the duplicate specimens at 70°F for 7 days in a sealed container to prevent moisture loss. The second and third procedures required curing the test specimens under accelerated conditions, at 100°F, for 7 days in sealed containers. Upon completion of the accelerated curing time, specimens for one procedure were soaked for 4 hours, and the remaining procedure called for vacuum saturation. All procedures are prescribed in ASTM C593, and the specimens were subsequently tested for unconfined compressive strength.

Recently, several agencies have experimented with the use of drainable pavement systems for heavy-duty pavements on interstate systems or other major roadways. These permeable base systems are designed to carry excess runoff water, which can infiltrate the pavement surface quickly to a pipe drainage system. These materials may use either an asphalt- or cement-treated stabilized mixture. The aggregate gradation is a compromise between two factors—permeability/durability or compressive strength. The intent is to have a very coarse aggregate matrix with a minimal fine aggregate content (material passing No. 200 sieve). This lack of fines will produce a very open and permeable graded matrix: the less fine aggregate used, the more permeable the mixture, a key design criterion. However, as more coarse-grained materials are used, the stabilized, hardened mixture becomes much less durable and susceptible to deterioration as construction equipment, trucks, etc., are driven over it. Therefore, an ideal gradation of aggregates has to be developed that will allow an open-graded matrix while exhibiting durability. Cement-treated permeable bases (CTPB) usually contain about 200–250 pounds of cement for a cubic yard of material. Generally 0%–10% of the material will pass the No. 8 sieve. The NDDOT will allow up to 4% finer than a No. 200 sieve. The cement content and aggregate gradation requirements will vary between agencies, often on an arbitrary basis. A range of mix designs may be more precisely tailored to specific job conditions, namely, the different levels of construction, trucking, and subgrade support conditions. These cement-treated bases have coefficients of permeability in the range of 3000–15,000 ft per day or approximately 1–6 cm per second (5). The compressive strength of CTPBs can vary from 150 to 600 psi at 7 days. Water–cement ratios can also be specified, but more significance should be placed on proper permeability requirements than on strength development.

Initial attempts at preparing permeable stabilized base course proved unsuccessful. The main reason for this was probably the large quantity of bottom ashes used. Initial blends of 50% coarse concrete aggregate and 50% bottom ash were used for the entire aggregate quantity. Even though the bottom ashes tend to have physical gradations similar to many concrete aggregates, they will still tend to have significant amounts of fines (material less than No.8 sieve). The NDDOT specification for aggregate use in a permeable base requires minimal amounts of materials passing the No. 8 sieve. The coal bottom ashes, with significant amounts finer than this size, produced a denser, less permeable concrete matrix.

A second attempt was made at blending coarse concrete aggregate, but at smaller ratios of bottom ash, which produced much better results in regard to high permeability. The percentage of total aggregate used for the Coal Creek, Antelope Valley, and Leland Olds bottom ashes was 20%. For the Coyote, Milton R. Young, and Heskett Stations, 15% of the total aggregate content was the bottom ash. The smaller quantities of bottom ash used in the aggregate blend resulted in gradations much closer to NDDOT specifications than were previously obtained. An alternative to using less bottom ash would be to separate most of the fines out of the bottom ash prior to blending with the concrete aggregate. This would allow the use of higher quantities of bottom ash. The intention of this task is to use a combination of coarse aggregate and bottom ash that will not require any additional separation or crushing in the field prior to use. The less handling required by either the contractor or utility company, the more appealing the application will be for using NDL by-products. A high water-to-cement ratio (0.71) was used to allow workability in the laboratory.

5.0 CONCLUSIONS

For concrete pavement design, the recommended fly ash replacement levels would be 35%–40%. Strength development appeared adequate to support traffic conditions. For bridge deck applications, where higher early strength development and resistance to corrosive salt solutions may be required, 25% to 30% fly ash use may be more appropriate.

CLSM results indicate substantial strength development in most of the fly ash mixtures. This is probably attributable to the high level of cement in the mix design. The recommended compressive strength of 100–150 psi at 28 days was surpassed in all but one instance at 14 days. A high compressive strength is not necessarily desirable in all CLSM instances, especially if future excavation is required. CLSM mixtures are ideal for fly ashes that do not strictly meet ASTM C618 specifications. All fly ashes examined here would be likely candidates for CLSM applications. The Heskett Unit No. 2 FBC fly ash and Leland Olds fly ash appear to have self-cementing properties ideal for this application. Although not examined in this task, bottom ashes could also be tested for use as granular filler in place of fine aggregate. The bottom ashes submitted for this project have a gradation similar to that of concrete aggregates.

For soil stabilization, the soil–fly ash–lime mixtures all significantly improved soil durability, but none of these mixtures achieved the minimum 400-psi compressive strength. Several reasons may explain this. First, as stated earlier, no attempt was made to determine optimum mix designs for any of the fly ash-containing mixtures. The prescribed proportions were similar to those found in related research using other fly ashes, which are not necessarily the optimum conditions for these fly ashes. Clearly, the use of cement, even in small quantities, will greatly enhance the durability of soil stabilization mixtures. To achieve the minimum strength of 400 psi, it is recommended either to use small quantities of cement in the test mixtures or to allow the samples to cure longer in their sealed containers.

All of the bottom ashes and slags exhibited acceptable performances for permeability and unconfined compressive strength. In all cases, strength development was substantial enough to allow removal from the cylinder molds one day after casting and later developed 7-day strengths comparable to the literature findings. The Heskett spent bed material (bottom ash) would be an ideal use in this application, although all of the bottom ashes seem to perform sufficiently well.

6.0 RECOMMENDATIONS

The EERC makes the following recommendations:

- It is recommended that near-term demonstration projects for the applications evaluated in this study be pursued through the NDDOT and other governmental agencies.

- The results indicate that the materials evaluated are environmentally suitable for utilization, and it is recommended that the NDSDH consider development of standards for preapproved uses for recycled lignite combustion by-products in road building and other use applications.

- Past demonstration and commercial projects utilizing Coal Creek Station fly ash in high-volume fly ash concrete should serve as examples for any future road building, other public works, and commercial projects in order to take full advantage of this high-quality North Dakota resource.

- Further work on the utilization of North Dakota bottom ash as aggregate in CLSM and other applications is recommended.

- The benign nature of the materials investigated recommends them for utilization in numerous other applications beyond road building. Specific needs that can be addressed in North Dakota by utilizing lignite by-products include mine reclamation, subsidence abatement, and skid control.

REFERENCES

1. Stewart, A.W. (1991) "Utilization of Low-Rank Coals Fly Ash in HHH Applications at a North Dakota Power Station," *In* Proceedings of the 16th Biennial Low-Rank Fuels Symposium; Billings, MT, May 20–23, 1991.

2. Dockter, B.A. (1995) "Scaling Resistance of Portland Cement Concrete Containing High Levels of Coal Combustion Fly Ashes," report prepared for Cooperative Power Associates.

3. Diamond, S. (1981) "Effects of Fly Ash Incorporation in Cement and Concrete," *In* Proceedings of the MRS Symposium; pp 12–23.

4. Dempsey, B.J. and Thompson, M.R. (1973) "Vacuum Saturation Method for Predicting Freeze–Thaw Durability of Stabilized Materials," Record No. 442; Highway Research Board, pp 44–57.

5. American Concrete Pavement Association. (1995) "Cement-Treated Permeable Base for Heavy-Traffic Concrete Pavements," IS404.01P.

WORKSHOP: INFORMATION IN THE ELECTRONIC AGE - HOW TO GET IT AND HOW TO USE IT

COMPARISON OF INTERNET AND DATABASE SEARCH ENGINES

Barbara Knight*, MA, MLS; Theresa Norton, MS; Phyllis Hustoft, MLS
Harley E. French Library of the Health Sciences, University of North Dakota, Grand Forks, ND 58202

ELECTRONIC JOURNALS: AVAILABILITY, ACCESS AND USAGE

Judith L. Rieke*, MLS; Theresa Norton, MS; and Michael Safratowich, MLS
Harley E. French Library of the Health Sciences, University of North Dakota, Grand Forks, ND 58202

COMPARISON OF INTERNET AND DATABASE SEARCH ENGINES

Barbara Knight*, MA, MLS; Theresa Norton, MS; Phyllis Hustoft, MLS
Harley E. French Library of the Health Sciences, University of North Dakota, Grand Forks, ND 58202

Information searching is a complex activity, dependent upon knowledge of principles, concepts, and techniques of information storage and retrieval. Scientists and healthcare professionals utilize a multitude of databases in retrieval of information vital to their research projects and the provision of competent patient care. The search engines used determine the results retrieved from the databases. The purpose of this paper is to present a comparison of the search engines used and the techniques necessary to maximize retrieval from a variety of databases. It will demonstrate the variability of search results and their dependence upon the attributes of the databases and search engines utilized.

Attributes considered will include extent of the database or search engine, currency, data manipulation, archival access, relevancy assignments, search quality, and availability of search aids. A demonstration of the similarities and differences of searching a database with controlled vocabulary versus natural language will highlight their effects on the quality of the search. "Controlled vocabulary and natural language each have advantages and disadvantages for information indexing and online information retrieval. The first is rigid, inflexible, and precise, the other is highly expressive, flexible, and potentially ambiguous (1)." Examples will be drawn from databases with controlled vocabularies, such as MEDLINE, as well as those which must be searched by utilizing natural language, such as the broad databases of the Internet and more specific databases, such as Current Contents.

Comparisons of search engines available for searching the Internet will be outlined in a similar manner. Specific search engines addressed will include, but not be limited to: Alta Vista, Deja News, Excite, HotBot, Infoseek, Jughead, Liszt, Lycos, Metacrawler, OpenText, Webcrawler and Yahoo.

1. Harter, Stephen P. (1986) Online Information Retrieval: Concepts, Principles, and Techniques, pp 54. San Diego, Academic Press.

ELECTRONIC JOURNALS: AVAILABILITY, ACCESS AND USAGE

Judith L. Ricke*, MLS; Theresa Norton, MS; and Michael Safratowich, MLS
Harley E. French Library of the Health Sciences, University of North Dakota, Grand Forks, ND 58202

Scientists, publishers, and librarians have long anticipated the age of the full text electronic journal. Access to full text e-journals was very limited until graphical World Wide Web browsers, such as Netscape and Internet Explorer, became widely available. Their development along with the common availability of powerful hardware makes the electronic journal more viable. The 1996 Association of Research Libraries Directory of Electronic Journals and Newsletters (1) listed nearly 2,000 electronic journals and newsletters available through the Internet. Although this represents only a small fraction of the number in print, this new medium is one that researchers should understand and utilize.

The purpose of this paper is to inform scientists how to locate and access electronic journals effectively. In addition, the strengths and weaknesses of the e-journal will be explained in relationship to scholarly research.

Finding electronic journals is becoming easier as they increase in number. Commercial publishers and professional organizations who produce them promote their electronic products extensively. Their advertisements as well as their actual print products list their "addresses". Libraries, such as ours, create links to selected journals through their home pages. There are also comprehensive lists and directories of scientific journals available for browsing. Many libraries note in the their catalogs, in our case ODIN, when their print titles have electronic counterparts. Often information is also included for titles not owned by the library, but whose subject matter is in scope for the library's users and collection.

A computer capable of connecting to the Internet either through a modem or a direct network connection is necessary to access electronic journals, For maximum utilization, one needs to use a World Wide Web browser like Netscape or Internet Explorer. In addition, the free Adobe Acrobat Reader software enables users to view, navigate through, and print any Portable Document Format (PDF) document in a form almost identical to that found in a print journal.

The strengths of electronic journals include quicker turn-around time for publication, desktop availability, interactivity of hyper-links throughout the text and references, the ability to request documents on demand, the ability to manipulate graphics (such as enlargement and reduction) and references (cut and paste into other documents or request forms). The weaknesses include the variability of the product, the pricing, licensing restrictions, security of the data, stability of the uniform resource location (URL) address, and the alteration of the peer review process. The issues of archiving and storing back issues are of special concern to scientists and librarians (2).

Electronic journals will change the system of scholarly communication as we know it. The benefits are undeniable, yet the challenges must be addressed. Electronic publishing needs the encouragement and participation of an informed scholarly community.

---

1. Association of Research Libraries Directory of Electronic Journals and Newsletters (1996) 6th edition. Association of Research Libraries, Washington, D.C.

2. Guthrie, Kevin M. And Wendy P. Lougee (1997) Library Journal 122, 42-44.

COMMUNICATIONS

UNDERGRADUATE

DISTRIBUTION OF PROTEOGLYCANS IN THE HUMAN SCLERA

Petra W. Fox*, Janice Audette, Edward C. Carlson, and Jody A. Rada
Department of Anatomy & Cell Biology, University of North Dakota
School of Medicine & Health Sciences, Grand Forks, ND 58202

The human sclera is a dense connective tissue consisting of collagen, proteoglycans, and non-collagenous glycoproteins. Although the sclera is typically viewed as metabolically inert, serving merely as a framework for the retina and retinal pigmented epithelium, disorders of the sclera can lead to severe visual impairment. Preliminary results indicate that the human sclera contains three major proteoglycans; aggrecan, a large chondroitin/keratan sulfate proteoglycan, biglycan, a small chondroitin/dermatan sulfate proteoglycan, and decorin, another small chondroitin/dermatan sulfate proteoglycan. Preliminary results also indicate that the relative amounts of each of these proteoglycans varies with the age of the sclera, as well as within different regions of the sclera. The goal of the present study is to localize aggrecan, biglycan and decorin within the anterior and posterior regions of the human in order to provide background information for future studies on disorders in which scleral anatomy and mechanical properties are altered.

For light-level immunohistochemistry, samples of anterior and posterior human sclera were embedded and frozen in OCT compound and sectioned using a cryostat. Frozen sections were mounted on gelatin coated slides and were digested with chondroitinase ABC to expose the protein core for subsequent immunolabeling. Immunostaining was carried out on frozen sections using the TrueBlue immunodetection kit (KPL, Goithersberg, MD). Scleral aggrecan was localized on tissue sections with an Fab' fragment specific for the human aggrecan core protein (generously provided by Dr. Robin Poole, McGill University); biglycan was localized using anti-human biglycan antibodies (1); and decorin was localized using an antiserum against a synthetic peptide containing the exon 5 sequence of human decorin (2). Following incubation with the specific antisera, scleral sections were washed, and incubated with goat anti-rabbit IgG conjugated to horseradish peroxidase. Sections were then washed, reacted with the TrueBlue peroxidase substrate and counterstained with KPL contrast red. For immunoelectron microscopy, scleral samples were fixed with 4% paraformaldehyde, dehydrated in n,n-dimethylformamide and embedded in Lowicryl K4M. Ultrathin sections were mounted onto nickel grids and used for post-embedding immunolabeling. Grids containing sections of anterior and posterior sclera were incubated with either anti-aggrecan, anti-biglycan or anti-decorin at 4°C overnight. Grids were then rinsed and incubated with goat anti-rabbit IgG conjugated to immunogold (30 nm diameter). Grids were rinsed, counterstained with uranyl acetate and lead citrate, and viewed by transmission electron microscopy.

Immunostaining of sections of human sclera with an Fab' fragment specific for the core protein of aggrecan suggested that aggrecan was concentrated on edges of scleral lamellae, with minimal staining within collagen fiber bundles. In contrast, immunostaining of frozen sections of human sclera with anti-biglycan and anti-decorin antisera indicated that biglycan and decorin were distributed throughout the thickness of the human sclera, in close association with most of the collagen fibers. Using immunoelectron microscopy with immunogold, the ultrastructural distribution of aggrecan, biglycan and decorin could be ascertained. Aggrecan appeared to be associated largely with non-collagenous material located between bundles of collagen fibrils, while decorin and biglycan were closely associated with most collagen fibrils, and were not located in spaces between fibril bundles. Immunogold immunostaining for aggrecan was reduced or largely absent from the anterior sclera as compared with staining in the posterior sclera.

Conclusions. The different distributions of aggrecan, biglycan and decorin within the human sclera suggest that these proteoglycans play different roles in regulating the physical and mechanical properties of the sclera.

Supported by a grant from NIH (EYO9391, JAR) as well as from the Howard Hughes Undergraduate Biological Science Education Program (PWF).

1. Roughley, P.J., White, R.J., Magny, M-D, Liu, J., Pearce, R.H., and Mort, J.S. (1993) Biochem J 295, 421.
2. Ramamurthy, P., Hocking, A.M., McQuillan D.J. (1996) J Biol Chem 271, 19578.

ANTIBIOTIC RESISTANCE AND OTHER VIRULENT FACTORS ASSOCIATED WITH *ESCHERICHIA COLI* STRAINS INCRIMINATED IN BOVINE CALF SCOURS

Darren Huber*, Mike Moen*, Paul Tessmann, and David G. White, Ph.D.
Department of Veterinary and Microbiological Sciences
North Dakota State University, Fargo, ND 58102

BACKGROUND

In today's world of high antibiotic usage in both the medical and agricultural fields, bacterial antibiotic resistance is becoming a prevalent trend and is cause for concern. Antibiotic resistant strains of bacteria are an increasing threat to animal and human health, and are making many of our current antibiotics obsolete. Compounding this problem is the fact that many of the more virulent bacterial strains have acquired resistance to multiple, structurally unrelated antibiotics. Often, these resistances are acquired with alarming ease. It is very possible that in the near future certain bacterial strains could become resistant to the effects of all known antibiotics.

PURPOSE

The purpose of our research was to collect data concerning the occurrence of multiple antibiotic resistance among *E. coli* strains incriminated in bovine calf scours in North Dakota. Bovine calf scours is a condition which afflicts young calves and is usually characterized by diarrhea and if not treated properly leads to death (1). Enterotoxigenic *E. coli* (ETEC) is recognized as the single most important bacterial cause of calf scours. By studying *E. coli* isolates taken from scouring calves, we sought to identify trends in antibiotic resistance in addition to screening for several virulence factors that have recently been identified in pathogenic *E. coli* strains.

METHODS AND RESULTS

More than 280 samples of *E. coli* taken from bovine calf scours cases were submitted to the NDSU Veterinary Diagnostic Laboratory during the year of 1996. Bacterial antibiotic sensitivities were carried out using standard antibiotic disk diffusion assays. Several of the antibiotics tested include: Amikacin, Ampicillin, Naxcel, Gentamicin, Tetracycline, Vetisulid, Sulfa drugs, Baytril, Lincomycin, Neomycin, and Spectinomycin. *E. coli* strains were also screened for the presence of several virulence factors: K-99 antigen (fimbriae that allow bacteria to adhere to the gut mucosa); Shiga-like-toxin genes 1&2 (SLT1, SLT2); enterohemolysin gene (HLY); and the *E. coli* attaching and effacing gene (EAE). Results showed which antibiotics were most effective and which strains possessed any of the above mentioned virulence factors.

The following data shows the six most effective antibiotics and six least effective antibiotics, respectively:

Amikacin	0 .7% resistant	(2/261)			Lincomycin	100% resistant	(262/262)
Baytril	7% resistant	(12/179)			Tetracycline	94% resistant	(246/262)
Naxcel	8% resistant	(21/261)			Triple Sulfa	87% resistant	(217/249)
Vetisulid	33% resistant	(87/260)			Neomycin	80% resistant	(209/261)
Gentamicin	35% resistant	(92/262)			Ampicillin	77% resistant	(202/262)
Tribrissen	54% resistant	(128/261)			Spectinomycin	73% resistant	(190/261)

CONCLUSIONS

Our testing showed that the drugs that are most available have the highest rates of bacterial resistance. This fact is disturbing because these drugs are oftentimes the first line of defense in combating calf scours. Our data supports the notion that use of Amikacin, Baytril, or Naxcel, along with electrolyte fluid therapy is the best available treatment for calf scours at the present time. The K99 antigen was found in 56% of strains associated with calf scours where as only 8% were enterohemolysin positive. We feel the best prospect for the future is the development of a greater understanding of how bacterial antimicrobial resistance occurs in combination with the development and use of effective control strategies.

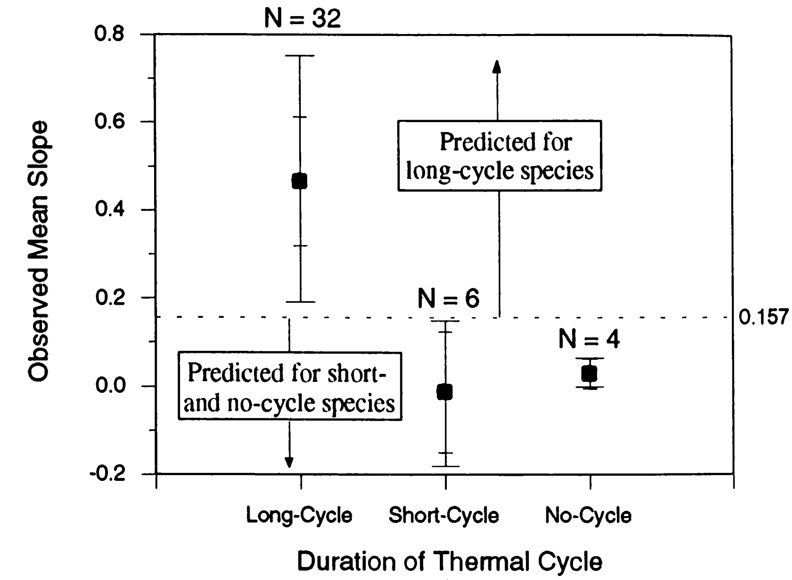
1. K. Wohlgemuth (1988). NDSU Extension Service. 15-AS 1-2.

EFFECTS OF ANNUAL TEMPERATURE CYCLES ON THE EVOLUTION OF TEMPERATURE PREFERENCE IN FISHES

Jennifer A. Johnson* and Steven W. Kelsch
University of North Dakota, Department of Biology, Box 9019, Grand Forks, ND 58202

Fishes prefer temperatures that reflect those experienced over their recent evolutionary histories and often shift preferred temperatures through acclimation to environmental temperatures. We developed and tested a hypothesis that these temperature-preference relationships were related to the amplitude of the annual thermal-cycle experienced by the species through their recent evolution. Species experiencing thermal cycles of relatively high amplitude (temperate species) and living in regions or habitats with an estimated annual temperature fluctuation of greater than 5°C (long-cycle) were predicted to have temperature preference relationships that were positive functions of acclimation temperature. Species that experience less than 5°C change in annual thermal amplitude but are exposed to short-term temperature fluctuations such as daily or weekly (short-cycle), and species that normally experience less than 5°C change in either annual or short-term temperature fluctuations (no-cycle) were predicted to have temperature preference relationships that were independent or negative functions of acclimation temperature.

Types of habitat and biological information were gathered from the literature to determine thermal cycles of fishes from which temperature-preference relationships were predicted. Published temperature-preference relationships were then examined to test our predictions. To establish whether observed temperature preference relationships were positive (slope > 0.157), negative (slope < -0.157), or independent (-0.157 < slope < 0.157) functions of acclimation temperature, we calculated the slopes of each observed relationship by performing a regression analysis on centered, ln by ln transformed data. Our hypothesis was strongly supported by the synthesis of studies from the literature (See figure). Of forty-two species of fish distributed among 11 families, for which both characteristics of thermal cycles and temperature-preference relationships were available, all exhibited slopes of temperature-preference relationships in the range predicted on the basis of their thermal cycle. Thirty-two species were observed to experience long thermal cycles, four experienced no cycles, and six experienced short cycles. The observed mean slopes, standard deviations (short bars), and ranges (long bars) for each category are shown in the figure. Only one of the eleven families examined had species that exhibited different classes of temperature-preference relationships, although four families were represented by only one species. Salmonidae (trouts and salmons), with eight species, exhibited temperature-preference relationships in each of the three classes.



It makes sense that species that experience substantial temperature changes would tend to evolve mechanisms that increase their metabolic efficiency following temperature change, and those with the time to acclimate would be favored to adjust their temperature preferences over time with exposure to changing temperature. Species in thermal environments with low temperature variation would not need to adjust their metabolism or temperature preferences, and those species that experience short-term temperature cycles would evolve broad thermal tolerances that do not require time for acclimation.

With further data analysis we believe that the amplitude of the long-term temperature cycle will also be correlated with the slope of the temperature preference relationship, and that the amplitude of the short-term temperature cycle will be correlated with the range of thermal tolerance.

This work demonstrates the adaptive nature of temperature-preference behavior and may be useful for predicting temperature-preference relationships for the majority of species not yet examined in this regard.

PROLACTIN REGULATION OF *bcl-2* FAMILY MEMBER GENES, *bad*, *mcl-1*, AND *bcl-x_L* IN Nb2-11 RAT LYMPHOMA CELLS

Sheri K. Kochendoerfer*, Donna J. Buckley, Kurt E. Borg,
Hugh Nguyen, Mingyu Zhang, Joshua Krumenacker, and Arthur R. Buckley
Department of Pharmacology and Toxicology, University of North Dakota School of Medicine and Health Sciences,
Grand Forks, North Dakota 58202-9037

Prolactin (PRL)-dependent rat pre-T Nb2 cell lines, initially derived from an estrogenized male Nb rat, serve as a powerful model for investigation of the mechanisms underlying lactogen-stimulated proliferation. Moreover, recent studies have demonstrated the utility of this paradigm for study of molecular events leading to programmed cell death (apoptosis). In this context, glucocorticoids such as dexamethasone (DEX) activate apoptosis in lactogen-dependent Nb2-11 cells; the addition of PRL abrogates the cytolytic actions of DEX in this model presumably due to its action to alter expression of apoptosis suppressor genes (1). In the present study, we investigated whether the demonstrated inhibition of DEX-activated apoptosis conferred by PRL reflected altered expression of *mcl-1*, *bcl-x_L*, or *bad*, Bcl-2 family members known to regulate the apoptotic process. Expression of each Bcl-2 family member was evaluated in PRL-treated, stationary Nb2-11 cultures by Northern blot analysis.

Total RNA was isolated from PRL (20ng/ml)-treated and control Nb2-11 cells, previously growth-arrested in the G1 phase of cell cycle, at time intervals ranging from 30 min to 24 hrs. The RNA was then quantitated spectrophotometrically, denatured in formaldehyde, and fractionated on 1% agarose gels, then transferred to Gene Screen Plus (DuPont, Wilmington, DE). Equal loading per lane was verified by ethidium bromide staining of 18S and 28S ribosomal RNA which was visualized and photographed under UV illumination. Membranes were hybridized with either *bad*, *mcl-1*, or *bcl-x_L* cDNAs (obtained from Dr. J.C. Reed, La Jolla, CA) labeled with [^{32}P]dCTP (DuPont NEN) using the random primer method of Feinberg and Vogelstein (2). Hybridization and wash procedures were performed using the methods of Church and Gilbert (3).

The results indicate that the 0.9 kb *bcl-x_L* transcript was rapidly induced by PRL. While *bcl-x_L* mRNA was absent in untreated cultures; it was detectable within 1 hr following the addition of PRL to the Nb2-11 cells. The *bcl-x_L* transcript subsequently accumulated to levels 9-fold greater than those detected in untreated-control cultures from 2-4 hrs before declining toward basal values. In contrast, PRL did not appear to affect *mcl-1* transcription. The 1.1 kb *mcl-1* transcript was found to be constitutively expressed in control and PRL-treated cultures at equivalent levels. Moreover, *bad* mRNA was not detectable under any of the experimental conditions evaluated.

We conclude that (1) *bad* and *mcl-1* are most likely not viable candidates for apoptosis regulatory genes stimulated by PRL in this model and (2) the kinetic pattern of PRL-provoked *bcl-x_L* expression is consistent with its playing a central role in conferring apoptosis resistance to Nb2-11 cells exposed to DEX in the presence of PRL. We suggest that *bcl-x_L* may represent an early intermediate apoptosis suppressor gene regulated by PRL in lactogen-dependent Nb2-11 cultures.

1. Leff, M.A., Buckley, D.J., Krumenacker, J.S., Reed, J.C., Miyashita, T., and Buckley, A.R. (1996) Endocrinology 137, 5456-5462.
2. Feinberg, A.P. and Vogelstein, B. (1983). Anal Biochem 132, 6-13.
3. Church, G.M. and Gilbert, W. (1984) Proc Natl Acad Sci USA 81, 1991-1995.

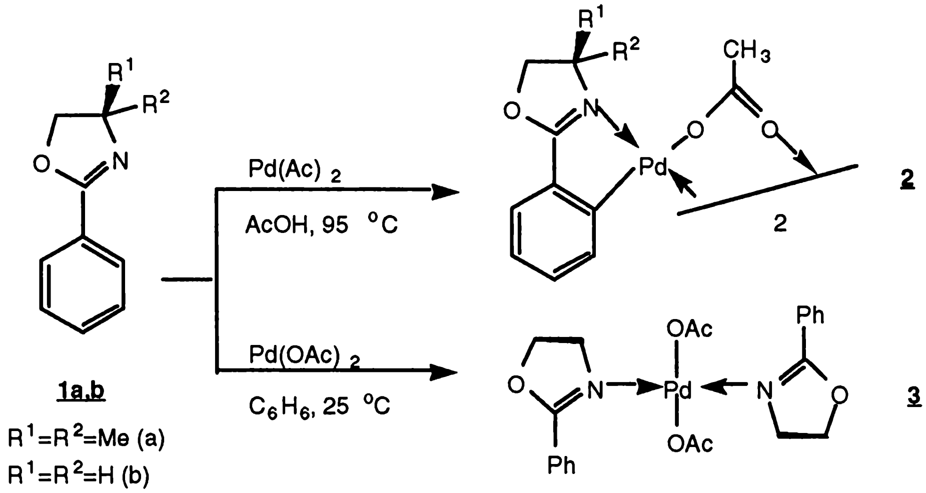
CYCLOPALLADATED COMPLEXES OF OXAZOLINES

Barry Leeks
Chemistry Department, University of North Dakota, Grand Forks, ND 58202

Previously, Balavoine and associates showed that 4,4-dimethyl-2-phenyloxazoline (1a) gives dimeric cyclopalladated complex (2a) by reaction with palladium acetate [1]. There has been much interest recently in similar cyclopalladated compounds because of their use as a catalyst in asymmetric syntheses. Optically active cyclopalladated compounds may also be used in the resolution of phosphines and some other chiral compounds.

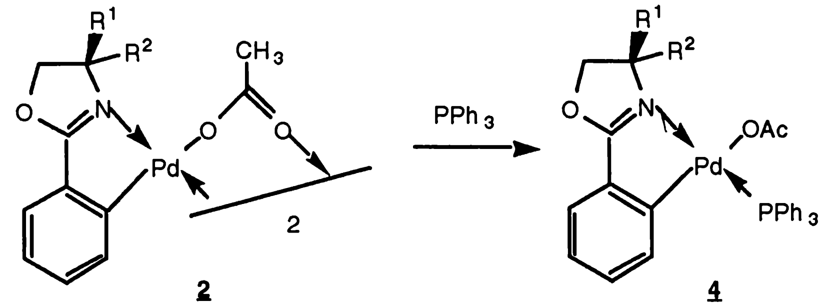
The purpose of this study is to prepare a number of chiral cyclopalladated complexes based on 2-phenyoxazoline by the procedure outlined in [1]. We found that 2-phenyloxazoline can be palladated with $Pd(OAc)_2$ in AcOH at 95°C to give compound 2b. The solvent used in the reaction has a profound effect on the product obtained, for example when benzene was used in place of acetic acid, the reaction yielded the coordinated complex 3. Structures of these compounds were confirmed by NMR spectroscopy.

Scheme 1



The dimer 2 can be converted to a monomer 4 by reacting it with PPh_3 as shown in Scheme 2.

Scheme 2



In the future we are planning to synthesize compounds based on optically active oxazolines bearing 4-alkyl groups to see if they can be used for the resolution of racemic phosphines.

1. Balavoine, G., Clinet, J.C., Zerbib, P. and Boubekeur, K. (1990) Journal of Organometallic Chemistry, 389, 259.

FARMERS' AND LANDOWNERS' PERSPECTIVES ON CONSERVATION PROGRAMS

Tiffany A. S. Parson*, Richard D. Crawford, and Glinda Crawford
Department of Biology, University of North Dakota, Grand Forks, ND 58202

In the summer of 1996, I designed and conducted a survey for Delta Waterfowl, Portage la Prairie, Manitoba. The purpose of the survey was to obtain farmers'[1] perspectives about a conservation program administered through Delta, the Adopt-A-Pothole (AAP) program. Additionally, the survey was designed to attain farmers' opinions about other conservation and wildlife issues. The survey contained 33 questions many of which required qualitative responses. A total of 39 people, 35 males and 4 females, were interviewed. All of the interviewees had leases with Delta in the AAP program. The method in which the survey was conducted was via personal interview (i.e., I drove throughout the state and personally interviewed each farmer).

Some of the main questions this survey was hoping to answer were the following: 1) Had farmers' involvement with the AAP program altered their farming practices? 2) After farmers' AAP leases ended, would the AAP land remain as grass or would it return to farmland? 3) How do farmers generally feel about the AAP program, wildlife, and other conservation programs?

The results of the survey revealed many interesting findings. Although one question directly asked if being involved with the AAP program had caused any changes in how farmers farm their non-AAP acres, I am positive that farmers viewed this question as derogatory. Almost all of the respondents (97%) immediately replied with a defensive "no" to this question. They likely thought I was asking this question to determine whether or not they had negatively altered their farming practices or to investigate if they had undermined their commitment to their AAP contract. There was no doubt some confusion concerning the focus of this question. However, I believe the responses to the question addressing what farmers will do with the AAP acres once their lease had ended clearly exemplified that farmers' agricultural practices had been positively altered due to their involvement with AAP. Over half of the respondents (54%) said they would keep part of the land that is in AAP as grass after their lease expired (or they already have kept part of the AAP land as grass, i.e., their lease had ended prior to the survey). This percentage did not include the respondents who said they would re-enroll in another conservation programs once their lease expired. Additionally, 59% of the respondents either currently idle land without compensation to benefit wildlife or plan to idle land for wildlife benefit in the future.

According to 51% of the farmers, the most important benefit of the AAP program was the monetary compensation. However, 38% of the farmers felt that preserving the land for wildlife use was the most important benefit of the program. Most of the respondents (69%) rated their overall experience with Delta and the AAP program as excellent. Moreover, 40% of the respondents indicated that their involvement with the AAP program has made them more likely to be involved with wildlife programs in the future.

Most of the interviewees (90%) felt it was either very important or important for them to see wildlife on their land. Moreover, 72% of the respondents attributed AAP as the catalyst for increased wildlife on their lands.

A majority of the respondents (67%) felt that conservation programs were always or usually necessary to protect wildlife. Additionally, 82% of the interviewees replied that conservation programs were very effective or effective at protecting wildlife. Some of the farmers (23%) preferred being involved with private organizations and programs, such as Delta, as opposed to governmental agencies, such as the U. S. Fish and Wildlife Service. Many of the farmers (54%) indicated that wildlife agencies could enhance their relationships with farmers through improvement of their communication skills and better cooperation.

I believe the survey results facilitate a better understanding of farmers' viewpoints on conservation and wildlife issues. Although the sample size for this survey was small, this study provides a template for further research in this area. Studies such as this are necessary for numerous reasons such as they help funding agencies decide if programs should be continued, they help biologists understand farmers' perspectives, and they provide valuable information for the improvement of conservation programs.

---

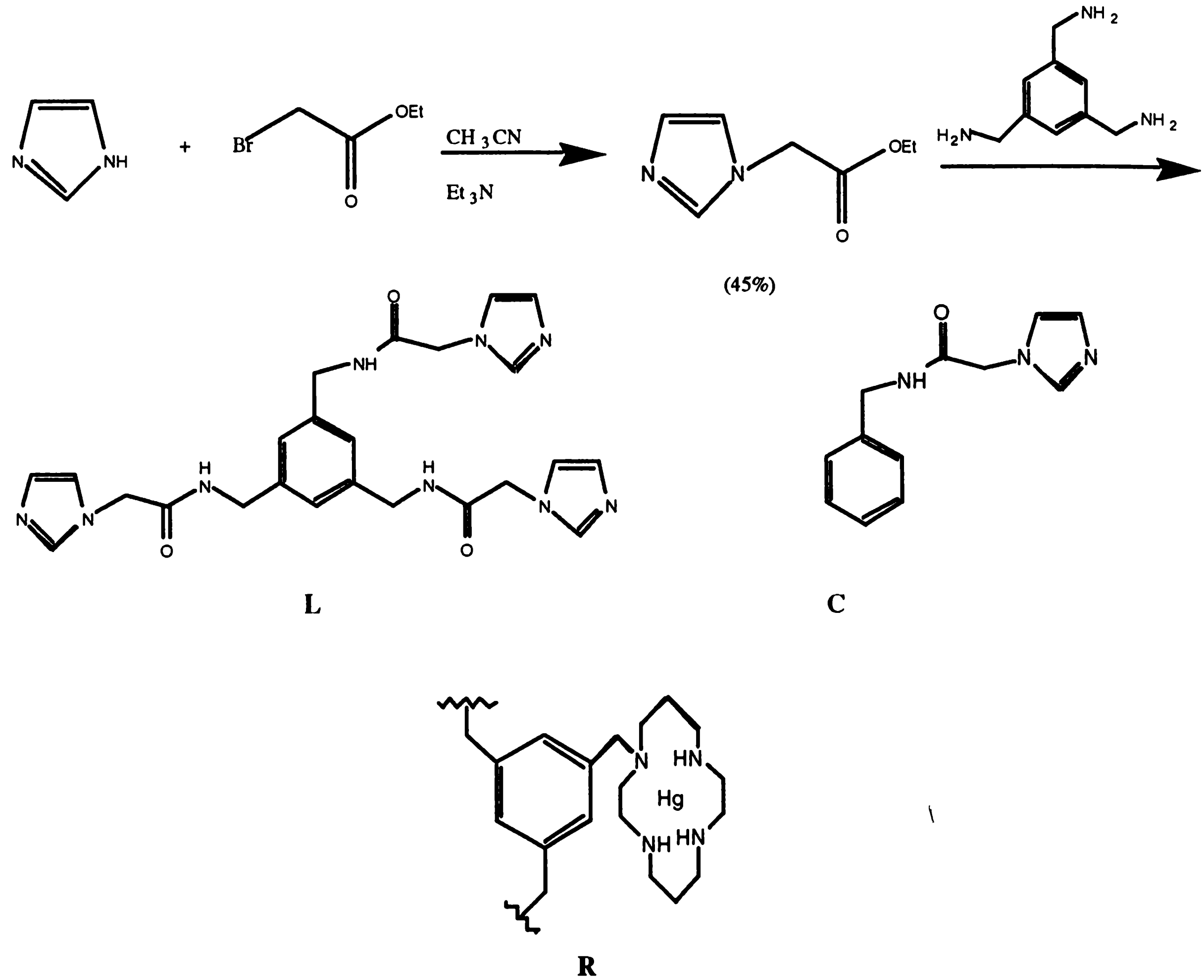
[1] Although both farmers and landowners were interviewed, for simplicity I will refer to all of the survey respondents as farmers.

MODEL STUDIES WITH A SYNTHETIC LIGAND AND ITS RECEPTOR

Jennifer Saltmarsh and Sanku Mallik*
Department of Chemistry, University of North Dakota
Grand Forks, ND 58202-9024

The research that I intend to present deals with model synthetic receptors and complementary ligands. Biological receptor-ligand interactions, like antibody-antigen interactions, are very selective and strong. They employ a large number of complementary and weak interactions. It is these interactions that we have been attempting to mimic. We have conducted initial model studies with synthetic receptors and ligands and we are now extending the studies to protein-liposome interactions.

As the first-generation model system, we have successfully designed and synthesized the ligand, L, to position three imidazole moieties ~ 12 Å apart (Scheme 1). The ligand was designed using the molecular modeling software 'Insight II' & 'Discover', (Version 95.0, BioSym/MSI, San Diego, CA). The organic frameworks were constructed in two dimensions and energy minimized (in gas phase) using consistent valence force field. Synthetic scheme is depicted below.



Scheme 1. Structures of the ligand (**L**), control (**C**), and receptor (**R**), used in model studies.

Initial recognition studies were conducted in a highly polar organic solvent, DMSO-d_6 and were followed by ^{1}H-NMR spectroscopy. These studies indicated that (**L**) forms a 1:1 complex with (**R**), with strong affinity (K_d < υm). Competition experiments indicated that (**L**) is indeed selective for (**R**), by a factor of 8 compared to the control (**C**). Studies are currently underway to improve the selectivity of this recognition process by systematically changing the ligand structure.

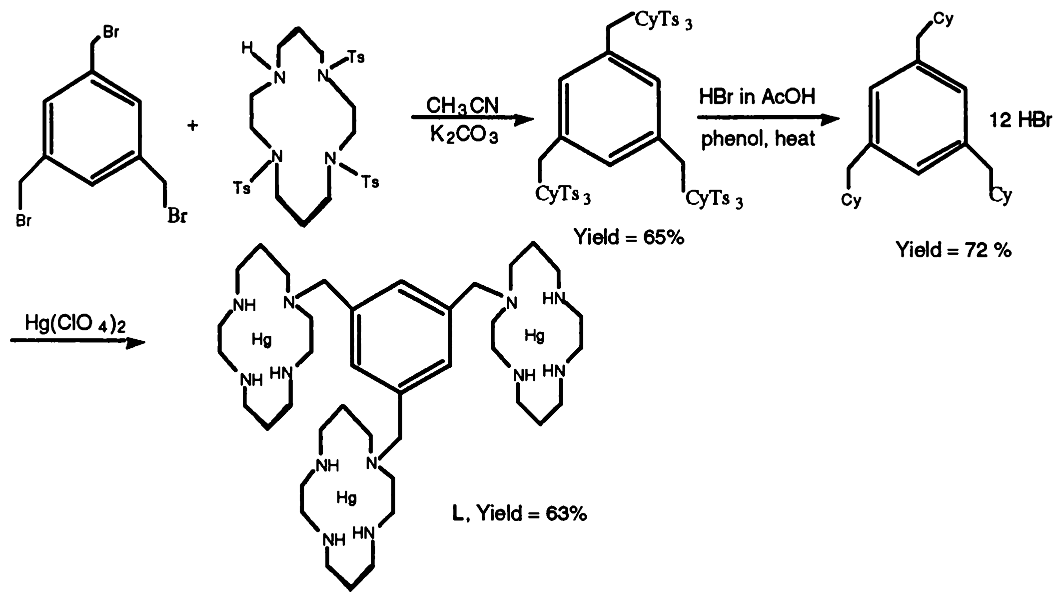
SYNTHESIS OF LIGANDS CAPABLE OF HOLDING THREE TRANSITION METAL IONS APPROXIMATELY 12 Å APART

Steve D. Scherer* and Sanku Mallik
Department of Chemistry, University of North Dakota
Grand Forks, ND 58202

We are interested in constructing model systems for mimicking biological receptor-ligand interactions. In order to achieve this, we are creating a pattern of metal ions on an artificial receptor, and matching the pattern with a designed ligand of complementary interacting moieties.

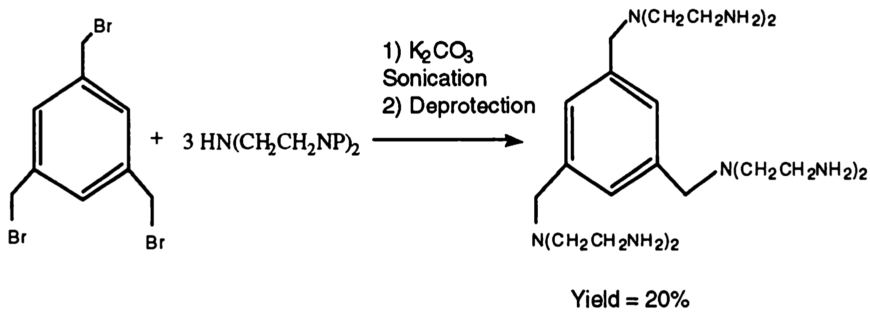
In order to demonstrate this, a receptor capable of holding three transition metal ions approximately 12 Å apart was first designed. The design was carried out on a Silicon Graphics workstation using software Insight II and Discover (version 95.0, BioSym Technologies/MSI, San Diego, CA). The receptor was designed in two-dimensions, converted to three dimensions, and energy minimized with a consistent valence force field in the gas phase.

The designed receptor has three 1,4,8,11-tetraazacyclotetradecane (cyclam) moieties to position the three transition metal ions. High affinities of cyclam for various transition metal ions (>10^{24} M^{-1}) ensure proper positioning of the metal ions. The synthesis of this tri-cyclam ligand and its tris-Hg^{2+} complex (L) is depicted in Scheme 1. In our initial studies, we chose a diamagnetic mercuric ion so that the interaction process can be followed by ^1H NMR spectroscopy.



Scheme 1. Synthesis of the tri-cyclam ligand and its tris-Hg^{2+} complex (L).

Currently we are involved in changing the ligand structure systematically without changing the inter-metal ion distances. Synthesis of one such ligand (diethylene triamine based) is depicted below. Optimization studies are in progress to improve the yields of this synthesis.



FIRST NORTH DAKOTA INFESTATION OF *MYRIOPHYLLUM SPICATUM*

Heather L. Schwehr* and Toni Legler
Department of Biology, Valley City State University
Valley City, ND 58072

On September 24, 1996, the first North Dakota infestation of *Myriophyllum spicatum* (Eurasian Watermilfoil) was discovered on the Sheyenne River in Barnes County. Due to the precedented nature of this aquatic plant it is imperative that professionals and the public alike be informed to facilitate management efforts by highlighting *M. spicatum's* history, biology, identification and conditions that influence the severity of Eurasian Watermilfoil problems and the resulting need for control.

Literature reviews, Internet searches and interviews with professionals with expertise on *M. spicatum* were conducted to gather the most accurate data available on the aquatic plant. The identified infestation was discovered while a group of ecology students were collecting aquatic vegetation on a transect of the Sheyenne River at Chautauqua Park in Valley City, North Dakota. Once the vegetation was collected it was taken back to one of the university's biology labs where it was identified as *M. spicatum*. At a later date, additional samples were collected and sent to Richard Couch of Oral Roberts University in Tulsa, Oklahoma for a conclusive identification. On October 22, 1996 word was received from Mr. Couch that the plant was indeed *M. spicatum*. After confirmation was received the Sheyenne River in Valley City was assessed for further infestations. The river was in a draw down stage making assessment of the river bed relatively easy. No new infestations were found outside Chautauqua park's boundaries.

According to Smith and Barko (1) *M. spicatum* is among the most troublesome submerged aquatic plants in North America. *M. spicatum* is native to Europe, Asia and Northern Africa. Its date of arrival in the United States is questionable do to misidentification. The first positive identification of the aquatic plant in the United States was in 1942 in a Washington D.C. pond. It has now been identified in 44 of the lower 48 states

M. spicatum can be identified by leaves in whorls of 3-5 at each node with 14-21 leaflets, typically with a red stem (absent in Sheyenne River specimens) (2) . The plants collapse once out of water. It is often confused with *Myriophyllum exalbescens* (Northern Watermilfoil), DNA analysis may be required if identification is questionable.

M. spicatum's growth pattern and adaptive ability make it particularly difficult to control. The roots are adventitious, rising along lower, buried portion of the stem. Flowering occurs only once the plant reaches the surface (1). In the spring, once water temperatures climb to 15 C, spring shoots grow rapidly, lower leaves falling off due to shading. Once the shoots reach the surface, they tend to form a dense canopy, often displacing native vegetation. After flowering, plant biomass is greatly reduced due to fragmentation of the stems (1). *M. spicatum* is tolerant of broad temperature and pH ranges (5.4-11), it is also able to survive under ice.

Smith and Barko state that existing control techniques for Eurasian Watermilfoil are short lived and expensive (1). Washington, Minnesota, Wisconsin and Vermont are spending upwards of a million dollars a year for control. A variety of control techniques including chemical, mechanical, and biological are in practice around the country. Each area of infestation should be individually assessed. A reduction in *M. spicatum*, after initial infestation, has been observed at some sites where it has been left to adapt to it's new environment. Water draw down and manipulation have also served as effective means of control. Tennessee Valley Authority Reservoir Research had success with freezing plants exposed due to draw down (2). Public awareness and education are the most inexpensive and potentially effective means of preventing the spread of *M. spicatum* (2). Mechanical means of control include rototilling, harvesting and hand removal. Some chemicals in use are 2-4, D, Tricolpyr, Endothal and Diquat. Efforts are also being focused on biological control methods involving the use of grass carp, moth larva, a freshwater weevil *Euhrychiopsis lecontei* and a fungal pathogen *Microlepidiscus terrestrias*.

The threatening nature of this plant requires immediate attention to prevent further infestation of the states waters. Spring assessments will determine the extent of infestation. At present there is a pressing need to educate both professionals and the public to the nature of *M. spicatum* and preventative measures that should be in place before spring.

---

1. Smith, Craig S. and J.W. Barko. 1990. Ecology of Eurasian Watermilfoil. J of Aquat Plant Manage 28:55-64.
2. Couch, R. and E. Nelson. 1985. *Myriophyllum spicatum* in North America. *In*: L. W. J. Anderson (ed), Proceedings of the First International Symposium on watermilfoil (*Myriophyllum Spicatum*) and related Haloragaceae species. Aquat. Plant Manage. Soc., Washington, D.C. pp.1-7.

DETERMINATION OF THE GENETIC MATING SYSTEM OF A NEO-TROPICAL PARROT USING MICROSATELLITE GENOTYPE DATA

Patricia Szczys* and Colin Hughes
Department of Biology, Box 9019, University of North Dakota, Grand Forks, ND 58202

Introduction. The mating system of a population is a description of how individuals find mates, how many mates they take, and how parental care is divided (1). In a monogamous mating system one male pairs with one female; though rare among animals in general, over 90% of bird species are classified as monogamous (2). But the seemingly humdrum social behavior, mate fidelity and shared parental care, obscures great variation in this mating system (3). Of relevance to this study, females may choose to mate with males other than their social mate (extra-pair fertilization, EPF), and to lay eggs in other females' nests (conspecific brood parasitism, CBP) reviewed in (4, 5). Use of modern molecular techniques allows description of the genetic mating system, a description of reproduction within and outside the pair. Studies of temperate bird species document that 0 to >60% of offspring may result from EPF, and that the rate of CBP may exceed 10%. Comparable data have not been published for tropical species, even though variables thought to influence the rates of EPF and CBP are known to differ between the regions. Tropical species are not constrained to short breeding seasons so nesting is expected to be less synchronous. Males are therefore expected to have greater access to fertile females, so the rate of EPF may be higher. Similarly, females may be able to complete their own clutches and then find still-laying females to parasitize. In this study we make one of the first determinations of genetic mating system for a neotropical bird, the Green-rumped parrotlet (*Forpus passerinus).*

Results. Two highly polymorphic microsatellite loci were scored for all individuals. Locus 7 had 14 alleles that ranged in frequency from 0.01 to 0.21; locus 91 had 18 alleles that ranged in frequency from 0.01 to 0.19. In 24 of the 30 families analyzed these loci did not exclude either social parent as being the biological parent. In the remaining 6 families, we were able to exclude one or both social parents as biological parents of one or more offspring. Of 141 offspring, 9 had bands that did not match one or both social parents. These families were analyzed at two additional loci, loci 54 and 98 which had 7 alleles each. Genotypes of two extra-pair offspring excluded the male but not the female social parent, consistent with EPF. Genotypes of two other extra-pair offspring excluded both social parents, consistent with CBP. The genotypes of the remaining 5, exclude the female, but not the male, social parent.

Methods. Samples were collected during summer of 1991 from the population of individually marked parrotlets on Hato Masaguaral, in the llanos of Venezuela. The birds nest in boxes provided along fence lines, which allows easy access to the nestlings(6). Approximately 10-20ul of blood was collected from the brachial vein. In the lab, DNA was extracted using Proteinase K digestion followed by organic extraction. Microsatellite loci were amplified from the samples, incorporating radioactive sulfur using this regime: 90s @ 92°C, then 0s @ 92°C, 0s @ 55°C, 5s @ 72°C, thirty times, and finally 90s @ 72°C. The radioactive products of amplification were run through 6% acrylamide 'sequencing' gels, dried, and exposed to film. 195 individuals comprising 30 families were genotyped at 4 polymorphic loci.

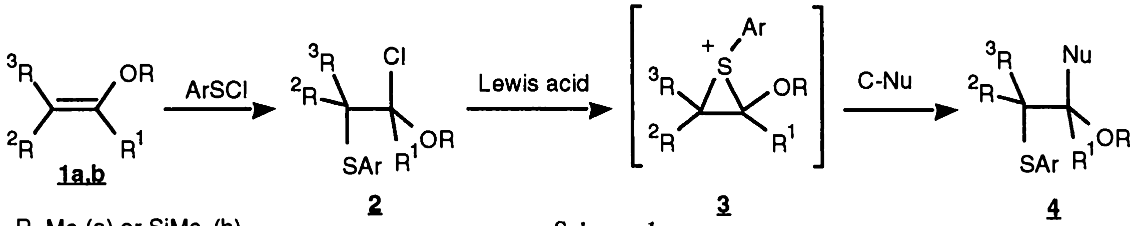
Discussion. The microsatellite loci used, exhibit sufficient polymorphism to describe the genetic mating system of this species. Green-rumped parrotlets are primarily (83% of pairs) monogamous. There is, however, a low frequency of EPF and CBP. More interesting, is the exclusion of female social parents in 6.6% of nests. This is consistent with one of two possible explanations. First, males be mated to two females who lay in the same nest; second males may be switching mates. The 'birth order' of the extra-pair offspring suggests the first explanation is more likely correct. Further no field observations of these nests record the occurrence of mate loss, or mate switching. The frequencies of extra-pair young in nests of the Green-rumped Parrotlet are qualitatively similar to those of many temperate birds despite the difference in duration of season favorable for breeding. Additional data will be necessary to determine whether there is any relationship between nesting synchrony and genetic mating system.

1. Emlen, S.T. & Oring, L.W. Science 197, 215-223 (1977).
2. Lack, D. Meuthuen and Co. Ltd. (1968).
3. Mock, D.W. & Fujioka, M. Trends Ecol. Evol. 5, 39-43 (1990).
4. Birkhead, T.R. and Møller, A.P. *Sperm competition in birds* (Academic Press, London, 1992).
5. Gowaty, P.A. and Bridges, W.C. *Behavioral Ecology* 2, 339-350 (1991).
6. Beissinger, S.R. & Stoleson, S.H. Acta XX Int. Ornith. Cong., 1727-1733 (1991).

REACTION OF CARBON NUCLEOPHILES WITH ArSCl ADDUCTS OF SILYL ENOL ETHERS

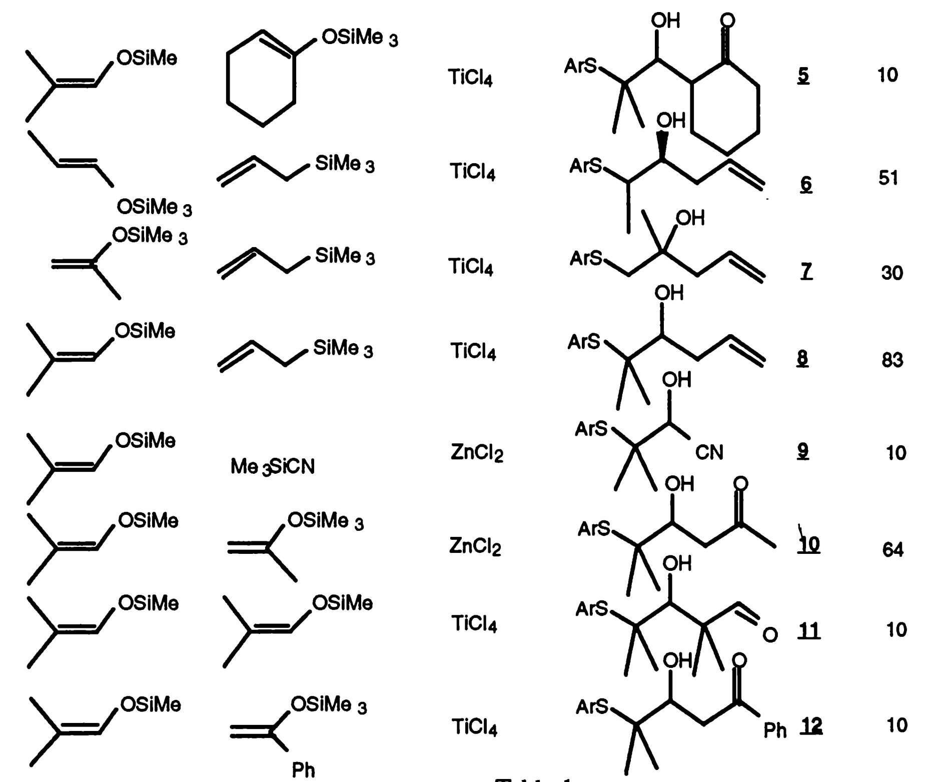
Scott Tschaekofske
Chemistry Department, University of North Dakota, Grand Forks, ND 58202

It has been shown that stepwise electrophilic addition is possible with ArSCl adducts of vinyl ethers (1a) through the formation of a stable intermediate, the episulfonium ion (ESI, 3) (1). The focus of the present study is to use *p*-tolylsulfenyl chloride (TolSCl) adducts of silyl enol ethers (SEE, **1b**) to achieve this addition (Scheme 1).



Scheme 1

We have found that, in the presence of Lewis acids adducts 2b are capable of reacting with various carbon nucleophiles (C-Nu, see Scheme 1 and Table 1). Generally, a SEE was treated sequentially at -78° C in freshly distilled CH_2Cl_2 and an atmosphere of N_2 with TolSCl and a Lewis acid to form the ESI. A second SEE or a silane was then added as the C-Nu to form a new C-C bond. After stirring for two hours at -78° C, the reaction mixture was quenched with aqueous $NaHCO_3$ or water, extracted, and dried with Na_2SO_4. Preparative TLC separated the desired product from the crude material. IR, mass, ^{1}H NMR, and ^{13}C NMR spectroscopy were used to confirm the structure of the final products (5 - 12).



original SEE	C-Nu	Lewis acid	Product		Yield, %
[structure]	[structure]	$TiCl_4$	[structure]	5	10
[structure]	[structure]	$TiCl_4$	[structure]	6	51
[structure]	[structure]	$TiCl_4$	[structure]	7	30
[structure]	[structure]	$TiCl_4$	[structure]	8	83
[structure]	Me_3SiCN	$ZnCl_2$	[structure]	9	10
[structure]	[structure]	$ZnCl_2$	[structure]	10	64
[structure]	[structure]	$TiCl_4$	[structure]	11	10
[structure]	[structure]	$TiCl_4$	[structure]	12	10

Table 1

The advantage of adducts 2b is the formation of the hydroxyl group in the products 5 - 12. These products are aldol compounds which can be used as precursors for the synthesis of numerous physiologically active compounds.

Thus, we have found that adducts of SEE can be reacted with various C-Nu to result in polyfunctional compounds.

1. Smit, W.A., Caple, R. and Smoliakova, I.P. (1994) Chem Rev 94, 2359.

A LABORATORY STUDY OF SEXUAL AGGRESSION IN UNDERGRADUATE MALES

Rod J. Wawryk*, Margo A. Norton, and Jeffrey E. Holm
Psychology Department, University of North Dakota, Grand Forks, ND 58202

This study examined a laboratory analogue of sexual aggression in male undergraduates. Approximately 1 in 12 women in the United States will be raped during their life. Research in this area has examined many variables including personality characteristics, life history factors, attraction to sexual aggression, attitudes toward women, and situational stimuli. In the past sexual aggression has been difficult to address in the laboratory under controlled conditions because one cannot permit a subject to act in a sexually aggressive manner toward another subject or even a confederate and because of the difficulty designing an appropriate analogue for the behavior. However, recently Gordon Hall at Kent State University has developed a procedure for examining what appears to be a mild form of sexual aggression (i.e., sexually impositional behavior) in the laboratory. This procedure was used in the present study to examine the extent to which attraction to sexual aggression, previous sexually aggressive behavior, and social demand/disinhibition influenced a male subject's propensity to act in a sexually impositional manner in the laboratory.

Male subjects (N = 115) were selected based on responses to two self-report measures: Sexual Experiences Survey and Attraction to Sexual Aggression Scale. Three subject groups were formed: a) a low sexually aggressive and low attraction to sexual aggression group (lo/lo), b) a high sexually aggressive and high attraction to sexual aggression group (hi/hi), and c) a low sexually aggressive and high attraction to sexual aggression group (lo/hi). Subjects were then randomly assigned to either a social disinhibitor condition or the control condition (i.e., no social disinhibitor).

Subjects were tested in conjunction with a confederate posing as a second subject. Subjects were told that we were studying media portrayals of sex and violence and were shown four clips in a random order from commercial films. They were told that they would then select one of the clips to show to a female subject who supposedly was in a separate room. Two clips were considered positively arousing (My Life and Running Man), one clip was considered negatively arousing but not sexual (Alive), and one clip was considered to be negatively arousing and sexual (I Spit on Your Grave). All clips were approximately one and a half minutes in length. Following the viewing of the four clips, the procedure varied according to whether the subject was in the social disinhibition or the control condition. In the social disinibition condition, the confederate remarked to the subject that he was going to show the clip from I Spit on Your Grave to the female subject. The experimenter then immediately returned to the room and escorted the confederate to another room under the pretense that he needed to wait while the subject chose his clip to show the female. In the control condition, the confederate made no remarks before the experimenter returned to the room to escort him to another room. The subject then was told to make his selection and to insert the videotape of the clip into a VCR to show to a female subject in another room. The subject then saw a videotape of a woman watching the clip he had chosen; however, he was led to believe that he was watching a closed-circuit monitor of an event that was actually occurring at that time. Following this the subject completed a brief questionnaire inquiring about the film clips and his perceptions of the woman's reactions (the videotapes of the woman "reacting" were identical and only showed the woman from the back - no discernible reaction could be observed).

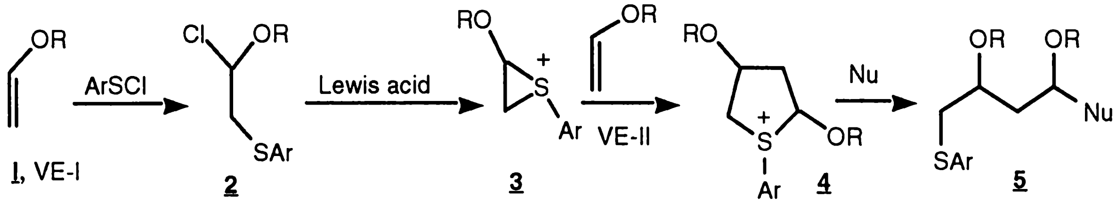
Analyses revealed that the sexually aversive clip was chosen by 31% of the subjects in the social disinhibitor condition and only 11% of the subjects in the control condition. A backward logistic regression was used to determine the significance of past sexually aggressive behavior, attraction to sexual aggression and the social disinhibitor in predicting selection of the sexually aversive clip. Analyses revealed that only the social disinhibitor was needed to create a significant model of prediction [X^2 (1, $\underline{N}$ = 115) = 7.092, $\underline{p}$ = .01]. The exponent (B) index revealed that subjects in the social disinhibitor condition were 3.66 times more likely to choose the sexually aversive clip than were subjects in the control condition. Further chi-square analyses provided some support for the hypothesis that the social disinhibitor would have a greater effect in the hi/hi group than the other two subject groups. These analyses showed that subjects in both the lo/lo and lo/hi groups in both the social disinhibitor and the control conditions, were significantly more likely to select a clip other than the sexually aversive clip. In the hi/hi group, chi-square analysis showed a similar effect in the control condition [X^2 (1, $\underline{N}$ = 14) = 7.14, $\underline{p}$ < .01] but not in the social disinhibition condition [X^2 (1, $\underline{N}$ = 15) = .067, $\underline{p}$ = .796]. Finally, two analyses of variances (ANOVAs) were used to examine the effect of clip selection and subject group on subjects' perceptions of the videotaped female's reaction to viewing the clip selected by the subject. These analyses showed that participants choosing the sexually aversive clip perceived the female as more uncomfortable [$\underline{F}$(2,115) = 46.06, $\underline{p}$ < .000] and as having a more negative reaction to the clip [$\underline{F}$(2,115) = 25.92, $\underline{p}$ < .000] than did subjects choosing any of the other three clips.

In conclusion, social disinhibition appears to have a dramatic effect on male undergraduates' willingness to behave in what seems to be a sexually impositional manner. This interpretation is strengthened by the fact that the subjects clearly expect the woman to be upset by their selection of the sexually aversive film clip. Interestingly, social disinhibition seemed to have an effect on subjects' behavior regardless of their past sexually aggressive behaviors and their attraction to sexual aggression. Nonetheless, some evidence suggested that the group high on both of these characteristics were more greatly effected by the social disinhibition condition. This laboratory analogue of sexually aggressive behaviors appears to improve our ability to study this phenomena and holds promise for aiding in attempts to better predict and modify sexually aggressive behaviors.

THE USE OF tert-BUTYL VINYL ETHER IN THE REACTION OF STEPWISE ELECTROPHILIC ADDITION

Dawn M. Wellman
Chemistry Department, University of North Dakota, Grand Forks, ND 58202

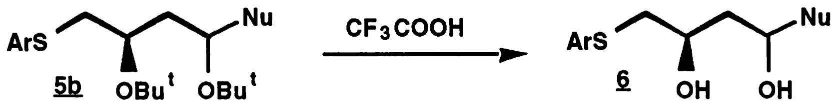
Recently it has been found that adducts of methyl vinyl ether (VE-I) (Scheme 1) are capable of reacting with another methyl vinyl ether (VE-II) to produce a five-membered cyclic intermediate (4) [1]. Intermediate 4 can be quenched with various nucleophiles, some of which include OMe, OH, H, CN, Grignard reagents, allylsilanes, and silyl enol ethers. The final products (5) are 1,3-methoxy derivatives which have other functional groups.



R=Me (a), Bu^t (b)

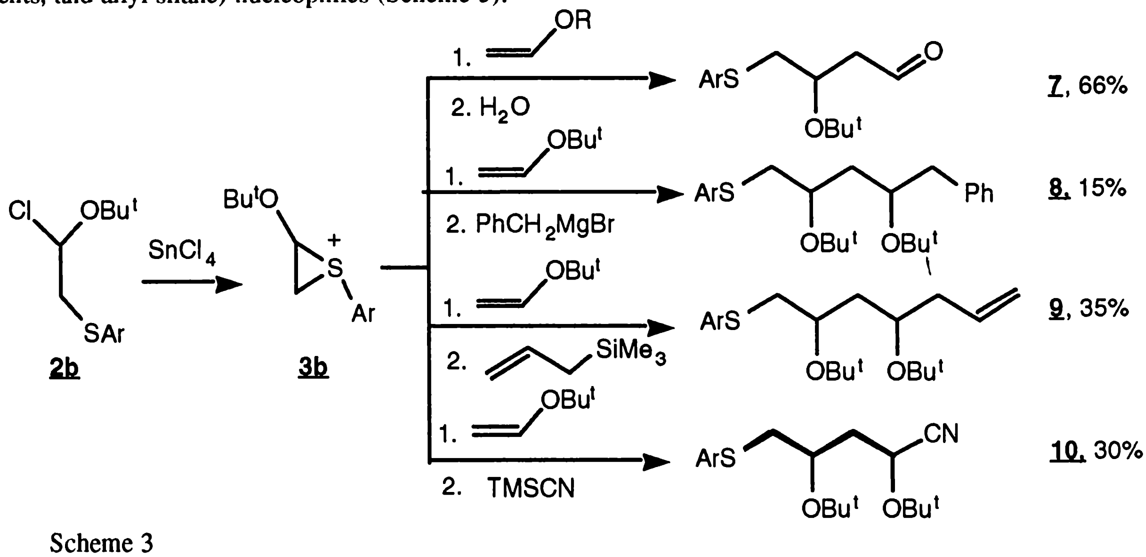
Scheme 1

The purpose of the present research is the study of similar reactions of a new vinyl ether, namely *tert*-butyl vinyl ether. This compound has been chosen for two reasons. 1) The *tert*-butyl group is an excellent leaving group. The final products 5 can be converted into corresponding 1,3-diols (6, Scheme 2). The presence of the additional functional groups in 6 makes them valuable precursors for synthesis of a number of naturally occurring physiologically active compounds that have a 1,3-diol moiety. 2) The *tert*-butyl group is one of the bulkiest groups; therefore, it was expected that the reactions would proceed with high stereoselectivity.



Scheme 2

We have found that *tert*-butyl vinyl ether reacts smoothly with ArSCl to afford adduct 2b. By treating the adduct with a Lewis acid an episulfonium ion (3) is produced. This can be quenched with O-(water) and C-(vinyl ethers, CN, Grignard reagents, and allyl silane) nucleophiles (Scheme 3).



Scheme 3

Thus, we have shown that tert-butyl vinyl ether can be used as a carbon nucleophile and as a precursor of an episulfonium ion (electrophile). The reactions studied are unique examples of stepwise electrophilic addition.

1. Smit, W.A., Caple, R. and Smoliakova, I.P. (1994) Chem Rev 94, 2359.

CYP1A1 GENE POLYMORPHISMS IN AFRICAN-AMERICAN AND CAUCASIAN PROSTATE CANCER AND NON-CANCER SUBJECTS

Timothy R. Wilkie, Sr.*, Kevin Gray, Mark A. Doll, Richard B. Hayes[1], Adrian J. Fretland, Anne C. Deitz, and David W. Hein
Department of Pharmacology and Toxicology,
University of North Dakota School of Medicine and Health Sciences,
Grand Forks, ND 58202-9037
and [1]Division of Cancer Epidemiology and Genetics,
National Cancer Institute, Bethesda, MD 20892-7364

Cytochrome P4501A1 (*CYP1A1*) is one of a family of cytochrome P450 monooxygenases that both deactivates and activates chemical carcinogens to electrophilic metabolites that bind to DNA and initiate tumors. *CYP1A1* is inducible, and a genetically determined high inducibility phenotype cosegregates with a polymorphism in a *Msp*I restriction site in the 3′-end of the *CYP1A1* gene. Another *CYP1A1* gene polymorphism induces a point mutation resulting in an amino acid substitution (Ile→Val) at amino acid 462 in the heme binding region of CYP1A1. Both *CYP1A1* polymorphisms have been associated with increased risk of lung and colon cancer.

Prostate cancer incidence and death rates vary markedly by race. Asians have a comparatively low incidence rate whereas African-American men have the highest prostate cancer incidence rate in the world. Family history is a recognized risk factor for prostate cancer, and one of the goals of our laboratory is to understand the genetic factors which predispose to this disease.

In collaboration with the National Cancer Institute, we determined *CYP1A1* genetic polymorphisms among black prostate cancer cases (n = 101) and controls (n = 111) and among white prostate cancer cases (n = 114) and controls (n = 121). DNA was isolated from blood samples collected from subjects of the cohort and *CYP1A1* was amplified by the polymerase chain reaction. The two *CYP1A1* polymorphisms were then identified by restriction fragment length polymorphism analysis to test for associations with prostate cancer incidence in Caucasians and African-Americans.

The distribution of *Msp*I alleles differed significantly between white and black case subjects (p = 0.03): among blacks the T/T, T/C, and C/C genotypes were (65.3% / 24.8% / 9.9%) and among whites they were 80.7% / 15.8% / 3.5%. The distribution of the *CYP1A1* (Ile→Val) alleles also differed significantly between white and black cases (p = 0.007): among blacks the A/A, A/G, and G/G genotypes were 98.0% / 2.0% / 0% and among whites they were 88.6% / 11.4% / 0%.

Risk for prostate cancer was determined by the calculation of age-adjusted odds ratios for the respective genotypes among cases and controls. With the common T/T genotype as the referent for the comparison of the *Msp*I alleles, prostate cancer cases had a 2.5-fold greater odds (p = 0.07) of carrying the C/C genotype than did controls. No increase in risk was found for the T/C genotype (odds ratio = 0.8). With the common A/A genotype as the referent for the *CYP1A1* (Ile→Val) alleles, the A/G genotype showed a significant excess among cases (odds ratio = 2.8; p = 0.04). Only 2 controls and no cases had the G/G allele, so determination of risk associated with that genotype was not possible.

These results suggest that both genetic polymorphism in the *CYP1A1* gene vary by race and may be risk factors for prostate cancer. This work was partially supported by USPHS grant CA-34627.

COMMUNICATIONS

GRADUATE

PALEOSOLS AS PROXY CLIMATIC CHANGE INDICATORS IN CENTRAL NORTH DAKOTA

Deborah L. Beck*[1] and Joseph H. Hartman[2]
[1]Department of Geology and Geological Engineering, University of North Dakota, Grand Forks, ND 58202-8358
[2]Energy & Environmental Research Center, University of North Dakota, Grand Forks, ND 58202-9018

The utility of paleosols as paleoclimate indicators has been recognized by many studies, including those that have focused on paleosols in the central Great Plains (1) and in löess paleosol sequences of China (2). In North Dakota, paleosols of the Oahe Formation have been studied for archeological (3) and stratigraphic significance (4), but paleoclimatic interpretations have been based only on meager evidence. In contrast, the Douglas Creek Locality of McLean County, North Dakota, with its multiple stacked paleosol sequence, may permit the interpretation of subtle changes in climate during a significant portion of the Holocene.

The Douglas Creek section, exposed on the north shore of Lake Sakakawea, consists of 15 buried A horizons. Textural and biogenic differences between individual soil horizons at this locality are being used to reveal small-scale environmental changes. The combined results of textural, radiocarbon, stable carbon, palynomorph, and phytolith analyses will permit reconstruction of the environmental history of the section.

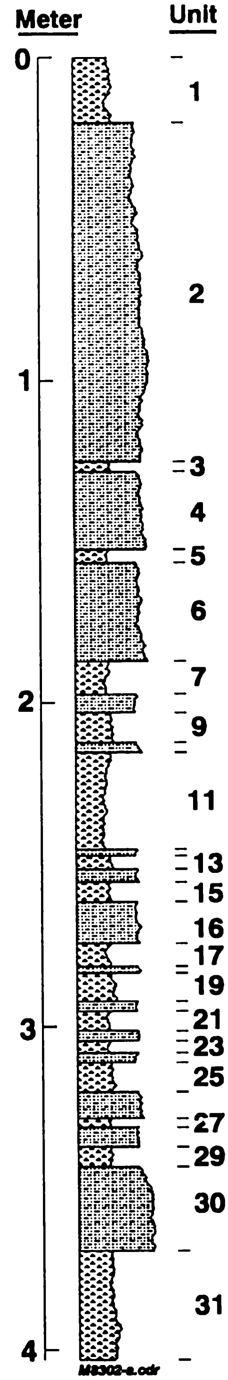
The Douglas Creek location is in a shallow valley fill that extends east–west a distance of 51.5 m. The Holocene section is up to 4 m thick. The buried soils consist of 15 sets of A and C horizons. Figure 1, a vertical section of the valley fill near its western edge, illustrates 15 sets of A and C horizons. Units 1 and 2 are modern A and C horizons, respectively. The odd-numbered units from 3 to 31 are Ab horizons. The intervening units represent Cb horizons. The average thickness of the Ab horizons is 5 cm, with a range of 2 to 34 cm. The Cb horizons are generally thicker than the Ab horizons, averaging 10 cm and ranging from 3 to 32 cm. Each Ab horizon is characterized by humus, lignite fragments, and its brown color (10YR 5/3). Cb horizons are free of organic material, olive in color (5Y 5/3), and, in many cases, have ribbons of carbonate. The grain size of the Ab horizons consists of clay ranging from 4% to 37% ($\bar{x}$ = 23.5%); silt ranging from 44% to 71% ($\bar{x}$ = 59.6%); and sand ranging from 6% to 30% ($\bar{x}$ = 17%). The ranges and means of grain size in Cb horizons are as follows: clay, 17% – 33% ($\bar{x}$ = 27%), silt from 47% to 60% ($\bar{x}$ = 54%), and sand from 8% to 26% ($\bar{x}$ = 19%). Comparison of Ab and C horizons reveals that silt is more abundant in A horizons and clay is more abundant in C horizons.

The radiocarbon dating of the paleosols conducted so far is promising. Three radiocarbon dates have been obtained. Bone samples from Units 7 and 11 were dated at 2090 ± 520 years and 3510 ± 295 years, respectively. Charcoal from Unit 17 was dated at 3800 years ± 45 years. Bone collected from Units 5, 9, and 11 as well as charcoal from Units 9, 21, 23, and 31 are expected to provide additional dates. Distinguishing between charcoal and Paleocene lignite clasts has been problematic. Fourier transform infrared analysis (FT-IR) of samples proved ineffective. Best results were obtained using luminescent petrographic analysis.

Preliminary $\delta^{13}C$ values range from −19.59 to −23.69 ($\bar{x}$ = −22.25). These values indicate that C_3 vegetation dominated the landscape during formation of most of the paleosols. Values from −19.59 to −21.94 in the uppermost buried soils suggests C_4 vegetation may have been present in the latter part of the formation of the section. Plants with C_4 metabolism (warm-season grasses) have the ability to efficiently concentrate CO_2 and thus are more productive under conditions of low atmospheric CO_2. C_3 metabolizing vegetation (trees, most shrubs, and cool-season grasses) fix O_2 at the expense of CO_2 under conditions of high temperature or low atmospheric CO_2.

Compilation of the current results leads to the hypothesis that the presence of the 15 Ab horizons is a result of long periods of stability during which pedogenesis was possible, followed by shorter periods of instability. These changes can be explained by small-scale climate changes at the site. The forthcoming results of the radiocarbon, $\delta^{13}C$, phytolith, and pollen analyses will be combined with the above results to test this hypothesis and interpret the scale of climate fluctuations.

Figure 1
Douglas Creek Section



1.) Woida, K. and Thompson, M.L. (1993) Geol. Soc. Amer. Bul. 105, pp 1445–1461.
2.) Verosub, K.L., Pinchas, F., Singer, M., and Tenpas, J. (1993) Geology 21, 99, pp 1011–1014.
3.) Kuehn, D.D. (1995) Ph.D. Dissertation, Texas A&M Univ.
4.) Clayton, L., Moran, S.R., and Bickley, W.B., ND Geol. Surv. Misc. Series 54.

RAPID METHODS OF SEPARATING VOC'S FROM AQUEOUS SAMPLES APPLIED TO HIGH-SPEED GAS CHROMATOGRAPHY

Robert W. Current* and Anthony J. Borgerding
Department of Chemistry, University of North Dakota, Grand Forks, ND, 58202

Volatile organic compounds (VOCs) are organic compounds with high vapor pressures (above ~0.1mm Hg at standard conditions) which are considered to participate in photochemical reactions which form ozone, and may pose other health and environmental risks. The United States Environmental Protection Agency has responded to the potential health and environmental risks arising from VOCs by requiring industries to monitor and minimize the production and use of these compounds. High-speed gas chromatography (GC) has become popular in the past few years, particularly for the detection and analysis of VOCs. However, most of the work done to this point has been on gaseous samples and does not address the sample handling needs of an aqueous matrix, which make up a larger portion of environmental and bioanalytical samples.

In this paper, we demonstrate the interfacing of aqueous sampling techniques with cryofocusing high-speed GC injectors. VOCs were removed from a water matrix using membrane techniques or extraction in a spray chamber. For analysis of VOCs, cryofocusing injectors can be used to concentrate the analytes at the head of the column before injection. This allows us to narrow the injection band, and thereby helps to reduce the time required for analyte separation. It is important that the time required for extraction be compatible with the rapid separation times in high-speed GC (less than one minute).

Membrane techniques can generate pulses of VOCs less than one minute in duration, depending on membrane transport conditions. We have also constructed a spray chamber where VOCs are extracted from aqueous samples of up to 1 mL in the nebulization process. This extraction process is very rapid, generating analyte pulses of just a few seconds. Specific extraction times and efficiencies are dependent on conditions such as flow rates of the extraction gas, extraction temperatures, and specific analyte properties. The system was carefully controlled to avoid plugging the cryofocusing injector with ice, and to prevent breakthrough of extracted analytes.

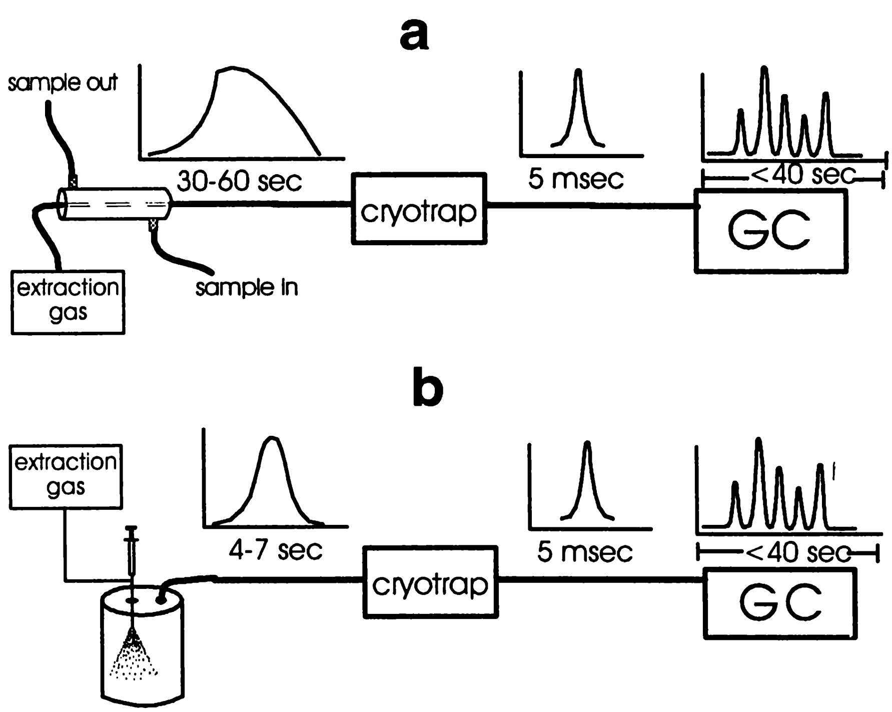
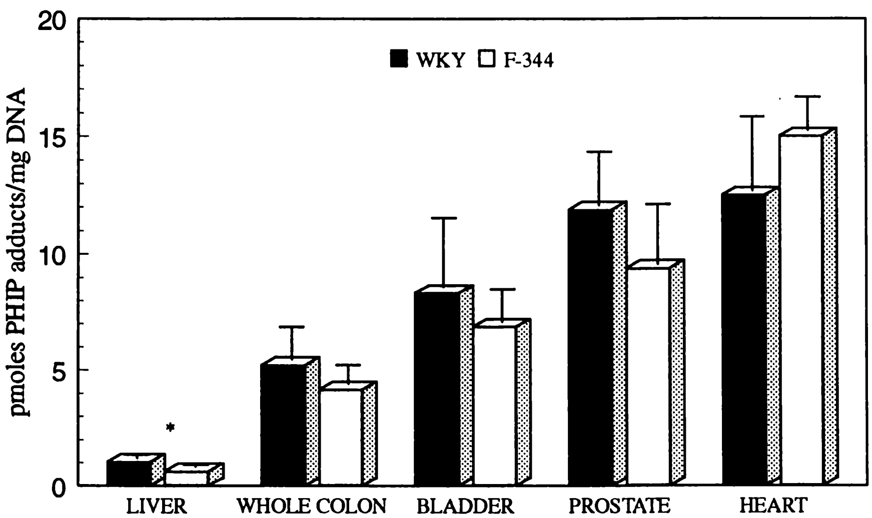


Diagram of Extraction Systems. a) Membrane System;
b) Spray Chamber System

DNA ADDUCT LEVELS OF 2-AMINO-1-METHYL-6-PHENYLIMIDAZO[4,5-b]PYRIDINE (PhIP) ADMINISTERED TO RAPID AND SLOW ACETYLATOR INBRED RATS

Adrian J. Fretland*, Yi Feng, and David W. Hein
Departments of Pharmacology and Toxicology, and Surgery
University of North Dakota School of Medicine and Health Sciences
Grand Forks, North Dakota 58202-9037

PhIP is the most common heterocyclic amine carcinogen in the human environment. The highest exposure to PhIP comes through the consumption of meats that have been cooked at very high temperatures. PhIP is also found in cigarette smoke. PhIP is a potent mammary carcinogen in female rats, as well as a potent colon and prostate carcinogen in male rats. PhIP has also shown to be cardiotoxic in rats inducing ultrastructural changes such as myofilament loss, sarcoplasmic reticulum swelling, and abnormal mitochondria. To exert its mutagenic effects, PhIP must undergo host-mediated metabolic activation *in vivo* to electrophilic intermediates which are capable of covalently binding to DNA. The formation of DNA adducts is the mechanism through which PhIP as well as other heterocyclic amines induce DNA damage which ultimately can lead to the formation of carcinogenic lesions. The metabolic cascade by which PhIP is bioactivated includes *O*-acetylation by the polymorphic *N*-acetyltransferase (NAT2). Rats as well as other mammals exhibit a well-defined polymorphism in acetylation capacity. This polymorphism in acetylation capacity is due to polymorphic *NAT2* alleles. Acetylator status is thought to be a predisposing factor in certain types of human cancers. We investigated the formation of PhIP-DNA adducts in rapid (F-344) and slow (WKY) acetylator inbred rats. Five rapid and five slow acetylator male rats received a single dose of PhIP(50 mg/kg body weight) by gavage. Control animals received vehicle alone. Animals were sacrificed at 24 hours, and target organs were collected. DNA was isolated by standard methods, and the level of PhIP-DNA adducts was measured by the ^{32}P-postlabeling method. The rank order of PhIP-DNA adducts in rapid and slow acetylator rats was heart > prostate > urinary bladder > colon >> liver. No significant differences in PhIP-DNA adducts were observed between rapid and slow acetylator inbred rats for any of the tissues examined except the liver. The level of PhIP DNA adducts was very low in the liver of both acetylator strains. These data suggest that DNA adduct formation may contribute towards the cardiotoxicity and the tumor formation in the colon and prostate of male rats administered PhIP.
Partially supported by USPHS grant CA-34627.



APPARENT LACK OF ASSOCIATION OF PROSTATE CANCER WITH N-ACETYLTRANSFERASE (*NAT2*) GENE POLYMORPHISM

Kevin Gray*, Mark A. Doll, Richard B. Hayes[1], Wen Jiang, Adrian J. Fretland, Venera Radu, Anne C. Deitz, and David W. Hein
Department of Pharmacology and Toxicology,
University of North Dakota School of Medicine and Health Sciences,
Grand Forks, ND 58202-9037
and [1]Division of Cancer Epidemiology and Genetics,
National Cancer Institute, Bethesda, MD 20892-7364

Adenocarcinoma of the prostate is currently the most commonly diagnosed cancer in men in the United States, and it is the second leading cause of cancer mortality in men. Despite its high prevalence, our understanding of the cause of this disease remains poor. Men with a family history of prostate cancer face increased risk of developing this disease. Prostate cancer incidence and death rates vary by race within the United States and by ethnic group throughout the world. Asians have a very low incidence of prostate cancer whereas men living in Western societies have a higher incidence. African-American men have the highest incidence of prostate cancer in the world. Heterocyclic amines present in the human diet and in cigarette smoke are prostate carcinogens in rodents. These chemicals undergo host-mediated metabolic activation to electrophilic intermediates that bind to DNA and initiate cancer. Major reaction pathways in this host-mediated metabolism include *N*-acetylation (deactivation) and *O*-acetylation (activation) catalyzed by polymorphic *N*-acetyltransferase (NAT2). Humans exhibit a genetic polymorphism in NAT2 activity, segregating into rapid, intermediate, and slow acetylator phenotypes. Polymorphic expression of *N*-acetylation and/or *O*-acetylation may be a differential risk factor in metabolic activation of heterocyclic carcinogens and susceptibility to prostate cancer. To test this hypothesis, we used restriction fragment length polymorphism analysis to determine *NAT2* acetylator genotype in an age- and race-matched cohort of prostate cancer and non-cancer (control) subjects collected by the National Cancer Institute. The polymorphic *N*-acetyltransferase gene (NAT2) was amplified by the polymerase chain reaction from DNA templates derived from blood samples of the prostate cancer and non-cancer subjects. Samples were analyzed for *NAT2* genotype. As shown below, no significant differences in *NAT2* acetylator phenotypes were observed between the prostate cancer subjects and controls, but the results suggest a slight overall decrease in risk (odds ratio 0.64) associated with rapid acetylator phenotype. Further analysis of *NAT2* and other susceptibility genes in the prostate cancer cohort is in progress.

	Non-Cancer (Control)	Prostate Cancer
Race	[Number (Percentage) of Subjects]	
African-American	111 (47.8%)	101 (47.0%)
Caucasian	121 (52.2%)	114 (53.0%)
Acetylator Phenotype		
Rapid	27 (11.6%)	17 (7.9%)
Intermediate	83 (35.8%)	79 (36.7%)
Slow	122 (52.6%)	119 (55.3%)

This work was partially supported by USPHS grant CA-34627 from the National Cancer Institute.

CHARACTERIZATION OF ATP- AND GTP-SPECIFIC SUCCINYL-COA SYNTHETASES IN PIGEON TISSUES

James D. Johnson* and David O. Lambeth
Department of Biochemistry and Molecular Biology, UND School of Medicine, Grand Forks, ND 58202

Succinyl-CoA synthetase (SCS) is a mitochondrial enzyme that catalyzes the only substrate-level phosphorylation step of the citric acid cycle: Succinyl-CoA + Pi + GDP (or ADP) → Succinate + CoA + GTP (or ATP). Succinyl-CoA synthetase is also believed to be required to produce succinyl-CoA for ketone body activation and heme biosynthesis.

The generalization that SCS is adenine-specific in plants, guanine-specific in animals, and relatively nonspecific in procaryotes had become widely accepted by the 1970s. However, Nishimura reviewed (1) a variety of evidence indicating that adenine-specific SCS can be found in animal species. Hamilton and Ottaway reported (2) that SCS activity in extracts of pigeon breast muscle is adenine-specific while that in liver is guanine-specific. The breast muscle enzyme was partially purified (3). Weitzman published data (4) indicating that adenine nucleotide supported activity is present in a number of mammalian animals and tissues. The long-term goal of our research is to characterize both forms of SCS in vertebrates, and to determine their relative expression in various tissues of representative mammalian species.

Procedures were developed for the isolation and purification of adenine-specific SCS (A-SCS) from breast muscle and guanine-specific SCS (G-SCS) from liver. Each procedure resulted in a preparation of SCS that was greater than 95% pure as indicated by SDS-PAGE. Each preparation showed two bands, representing the α- and β-subunits, at approximately 36 kDa and 43 kDa, respectively. When purified samples of A-SCS and G-SCS were mixed and run on SDS-PAGE, the α-subunits appeared as a single band, whereas the β-subunits appeared as a doublet. This was the first indication that the β-subunits of A-SCS and G-SCS are different.

Additional characterization of the two isozymes of SCS was carried out in a variety of physical and enzymological studies. Size exclusion chromatography demonstrated that both A-SCS and G-SCS have apparent molecular masses near 80 kDa, indicating that the native structure is an αβ heterodimer.

An HPLC-based assay was used to study the nucleotide specificity of each purified preparation of SCS. Reaction samples were injected onto a C-18 reverse-phase (RP) HPLC column. The rate of reaction was quantified by the amount of succinyl-CoA converted to CoA. Amounts of SCS which gave less than 12% conversion were used in order to keep the reaction linear. Specificity studies demonstrated that A-SCS could not utilize GDP and that G-SCS could not utilize ADP. Studies in the reverse direction exhibited similar results. Thus the isozymes of SCS, isolated from breast muscle and liver, clearly have different nucleotide specificities.

Kinetic studies indicated a difference in the K_ms of the respective nucleotides for A-SCS and G-SCS. Adenine-specific SCS had a K_m of 0.27 mM and 0.061 mM for ADP and ATP respectively, while G-SCS had a K_m of 0.007 mM and 0.032 mM for GDP and GTP respectively. This suggests that the isozymes may optimally catalyze the SCS reaction in opposite directions.

A method was established to futher purify and separate the α- and β- subunits of A-SCS and G-SCS by RP-HPLC. Purified samples of A-SCS and G-SCS were run on HPLC to establish independent retention profiles. The purified isozymes were also mixed and the profiles showed that the α-subunits had the same retention time, whereas the retention times of the β-subunits were clearly different.

Isoelectric focusing (IEF) gels of native A-SCS and G-SCS showed that A-SCS had a higher isolectric pH (pI) than that of G-SCS. This study was carried one step further by running a denaturing IEF gel to examine both holoenzymes and the HPLC purified subunits. The gel revealed that the α-subunits were similar, but the β-subunits were different for A-SCS and G-SCS. The pI for the A-SCS β-subunit was higher than that of the G-SCS β-subunit.

Finally, digestion with trypsin and RP-HPLC separation was performed on the individual subunits of A-SCS and G-SCS respectively. The individual profiles of the α-subunits appear identical, whereas those for the ß-subunits are very different.

In summary, this study demonstrates that two isozymes of SCS exist in vertebrates, one highly specific for ATP\ADP, the other for GTP\GDP. Characterization studies demonstrate that the α-subunits are identical, but the β-subunits are clearly different. This leads to the conclusion that although the α-subunit contains the phosphorylation site used in the catalytic mechanism (5), the β-subunit is responsible for determining the nucleotide specificity of each isozyme.

1. Nishimura, J.S. (1986) Advan. Enzymol. 58:141-172.
2. Hamilton, M.L. and Ottaway, J.H. (1981) FEBS Lett. 123:252-254.
3. Allen, D.A. and Ottaway, (1986) FEBS Lett. 194:171-175.
4. Weitzman, P.D.J., Jenkins, T., Else, A.J., and Holt, R.A. (1986) FEBS Lett. 199:57-60.
5. Bridger, W.A. (1971) Biochem. Biophys. Res. Commun. 42:948-954.

DECIPHERING THE NUMBER OF FOSSIL TURTLES AT THE ASH COULEE QUARRY IN BILLINGS COUNTY, NORTH DAKOTA

Glenn B. Kays*[1], Patricia H. Kelley[1], and John W. Hoganson[2]
[1] Department of Geology and Geological Engineering, University of North Dakota, Grand Forks, ND 58202
[2] North Dakota Geological Survey, 600 East Boulevard Avenue Bismarck, ND 58505-0840

Paleoecologists often try to reconstruct paleocommunities based on the number of individuals in a fossil assemblage. Various methodologies have been proposed for establishing relative numbers of individual species present within a fossil assemblage (1-3). In order to reconstruct the proper relationships within the energy cycle of a fossil assemblage, accurate relative abundances of taxa are needed. If all the levels of the trophic pyramid for a fossil population were represented, then the herbivores would outnumber the carnivores and so on. It is important to estimate the relative numbers of different taxa within a fossil assemblage in order to establish a proportionality between members of different levels of the trophic pyramid. A high degree of disproportionality in relative numbers of specimens (herbivores vs. carnivores) could mean a great deal of taphonomic influence has taken place.

Methods proposed in (1) give upper and lower limits, in numbers of specimens, to a fossil assemblage. The maXimum Number of Individuals, XNI, and Minimum number of Individuals, MNI, are two methodologies which can estimate the upper and lower limits of a fossil population. The XNI methodology estimates the upper limit of a fossil population by assuming that every bone in the assemblage represents a different individual. The MNI methodology estimates the lower limit of a fossil population. In this method the number of individuals for a certain species is represented by the most common bone element for that species. These estimates are over-and under-estimates; however, they create upper and lower limits for the number of specimens present in a fossil assemblage.

The Ash Coulee Quarry in the Paleocene Sentinel Butte Formation in Billings County, North Dakota, has been noted for its fossiliferous "turtle bed"(4). The turtle bed occurs in the lower portion of the Sentinel Butte Formation and is composed of a 6-10 cm. thick fissile shale layer. During the summers of 1995 and 1996 approximately 15 sq. meters of the turtle bed were excavated. The turtles occur as complete to disarticulated carapaces, plastrons, limb bones, and two skulls, belonging to the genus *Plastomenus* sp. The Ash Coulee Quarry is a death assemblage of plastomenid turtles. A death assemblage is an accumulation of highly disarticulated and abraded animal remains that have been transported from the original place of death and deposited elsewhere. The turtle remains at the Ash Coulee Quarry exhibit a high degree of overall body disarticulation, although many individual plastrons and carapaces are still articulated. Brand (5) has studied turtle disarticulation. The results of his study indicate that a turtle has to float for a period of 30 days before the head disarticulates from the body, and the carapace and plastron fall away from each other. The individual carapaces and plastrons, however, will remain articulated for up to 50 weeks in a low energy environment. At the Ash Coulee Quarry there are two skulls deposited among many articulated carapaces and plastrons. This indicates that many of the turtle bodies must have floated for up to 30 days after the time of their death, and prior to their final deposition.

The methodologies described by (1) can be used to put upper and lower limits on the number of turtle specimens present at the Ash Coulee Quarry. These methodologies have been slightly modified because of the turtle morphology. Instead of individual shell bones, we are using the numbers of relatively complete carapaces and plastrons to estimate the population limits. Gilinsky and Bennington (1) state that individual bones should be used; however, because of the high quality of shell preservation at this site, nearly complete shells can be used to estimate the population of turtles.

Thus far, at the Ash Coulee Quarry, 8 individual plastrons and 8 individual carapáces have been recorded. From these data we estimate that there are between 8 and 16 individual plastomenid turtles excavated from the site. This estimate represents the largest recorded assemblage of plastomenid turtles in North America to date.

1. Gilinsky, N.L., and Bennington, J.B. 1994. Estimating numbers of whole individuals from collections of body parts: a taphonomic limitation of the paleontological record. Paleobiology, 20(2): 245-258.
2. Holtzman, R.C. 1979. Maximum likelihood estimation of fossil assemblage composition. Paleobiology, 5(2): 77-89.
3. Behrensmeyer, A.K. 1991. Terrestrial vertebrate accumulations. Pp. 291-335 *in* P.A. Allison and D.E.G. Briggs, eds. Taphonomy: releasing the data locked in the fossil record. Plenum, New York.
4. Kays, G.B., Erickson, J.M., Hoganson, J.W. 1996. Systematics and Taphonomy of the Trionychoid Turtle *Plastomenus* from the Ash Coulee Quarry, Sentinel Butte Formation (Paleocene) Billings County, North Dakota. Proceedings of the North Dakota Academy of Science. 50: 33.
5. Brand, L. 1995. Personal Communication. Loma Linda University. Loma Linda, California.

CHARACTERIZATION OF p53-POSITIVE CLONES: INITIAL STEPS LEADING TO ENGINEERING A "KNOCK-OUT" MOUSE

Rebecca Kissner*, Hugh Nguyen, Janis Hulla
University of North Dakota, Department of Pharmacology and Toxicology

Objective: Isolate and clone the mouse p53 gene towards the development of a "tissue-specific" knock-out mouse model.

We have screened a mouse genomic library and obtained two clones, pBAC61 and pBAC193, that were initially presumed to contain all or part of the p53 gene. We grew up the clones and used the isolated DNA as our template for p53-targeted polymerase chain reaction. We have confirmed the presence of the complete gene within both of these plasmids. We are working to grow up and isolate large amounts of DNA for future use. The next step is to use restriction enzymes and cut the p53 gene out of the plasmid DNA. We want to do this in a way that will yield the largest portion of the p53 gene and minimize the excess genomic sequence that would flank the gene.

The long term goal is to use the loxP/Cre recombinase system toward the development of a tissue-specific p53 knock-out. The loxP/Cre system is a site-specific recombination system which consists of a 34 base pair sequence, loxP, that directs a recombination event catalyzed by the Cre recombinase. The system relies on site-specific chromosomal integration of a loxP-flanked p53 gene fragment and precise excision of the flanked gene sequence. Once developed, the model will be used as a source for cell culture and for in vivo experiments.

PROLACTIN-ACTIVATED SIGNALLING PATHWAYS LEADING TO *PIM*-1 EXPRESSION IN RAT Nb2-11 LYMPHOMA CELLS

Joshua S. Krumenacker*, Donna J. Buckley, Tim O. Raghib and Arthur R. Buckley
Dept of Pharmacology and Toxicology, Univ of North Dakota School of Medicine and Health Sciences, Grand Forks, ND 58202-9037

The prolactin (PRL)-dependent Nb2-11 lymphoma cell line is a useful model to investigate PRL signalling mechanisms leading to induction of transcription. Toward this end, numerous studies have suggested a role for the JAK2-STAT and ras-MEK-MAPK signalling pathways (1,2). Previously, we reported that PRL stimulated a rapid (<15 min) and robust (40-fold) induction of the protooncogene, *pim*-1, in stationary Nb2-11 cultures (3). In this study, we investigated whether specific protein kinases regulate *pim*-1 transcription using pharmacologic kinase antagonists. Each antagonist, including a specific inhibitor of JAK2 (tyrphostin B42), MEK-1 (PD98059), protein kinase C (PKC) (calphostin C), and a nonspecific inhibitor of tyrosine kinases (tyrphostin A25), caused a concentration-dependent inhibition of ^{3}H-thymidine incorporation in a 48 hr, PRL proliferation assay. Moreover, Northern blot analysis revealed that PD98059 and tyrphostin B42, at high concentrations (100µM), reduced PRL-stimulated *pim*-1 expression while tyrphostin A25 and calphostin C had no effect. However, the concentration of tyrphostin B42 that inhibited PRL-stimulated proliferation by 80% did not reduce hormone-provoked *pim*-1 mRNA expression. In other experiments, PRL was found to activate ZAP-70, a tyrosine kinase linked to T-cell receptor stimulation. In stationary Nb2-11 cells, PRL rapidly (2 min) stimulated tyrosyl phosphorylation of ZAP-70 determined by immunoprecipitation/immunoblot analysis. We conclude that inhibition of JAK2, PKC, and MEK blocks PRL-stimulated Nb2-11 cell proliferation. In addition, since concentrations of tyrphostin B42 that suppress PRL-stimulated proliferation are without an affect on hormone-induced *pim*-1 expression, the JAK2-STAT pathway may not mediate its transcription. Finally, the rapid activation of ZAP-70 by PRL suggests a potential role for this kinase as a mediator of *pim*-1 expression. Supported in part by grants from the NIH (DK44439), ACS (RD-383), AICR (95B089).

1. Rui, H., Kirken, R., and Farrar, W. (1994) J Biol Chem 269, 5364-5368.
2. Rao, Y., Buckley, D., Buckley, A. (1995) Cell Growth Diff 6, 1235-1244.
3. Buckley, A., Buckley, D., Leff, M., Hoover, D., Magnuson, N. (1995) Endocrinology 136, 5252-5259.

HUMAN *N*-ACETYLTRANSFERASE (*NAT1* AND *NAT2*) TRANSGENE CONSTRUCTS ENGINEERED TO DRIVE PROSTATE-SPECIFIC EXPRESSION IN MICE

Matthew A. Leff*, Mark A. Doll, Paul N. Epstein, and David W. Hein
Department of Pharmacology and Toxicology,
University of North Dakota School of Medicine and Health Sciences
Grand Forks, ND 58202-9037

PURPOSE: Genetic and environmental factors are associated with the etiology of prostate cancer. However, identification of mechanisms which underlie oncogenic progression remain to be elucidated. Human epidemiological studies suggest that genetic polymorphisms in enzymes which metabolize aromatic and heterocyclic amine carcinogens may predispose individuals to prostate cancer. Importantly, aromatic amine *N*-acetylation and the metabolic activation of *N*-hydroxyarylamines (via *O*-acetylation) are catalyzed by common acetyltransferases (NAT1 and NAT2) subject to genetic polymorphism. We propose to assess the effect of prostate specific overexpression of genetically polymorphic human NAT1 and NAT2 on expression of prostate specific *N*-acetylation and *O*-acetylation, and on DNA adduct formation which serves as a biomarker for tumor initiation, upon the administration of the carcinogens; 3,2′-dimethyl-4-aminobiphenyl, 2-aminofluorine, and 2-amino-1-methyl-6-phenylimidazo[4,5-b]pyridine. Herein, we describe the engineering of two (human *NAT1* and *NAT2*) constructs which will be utilized to direct prostate-specific expression of human *NAT1* and *NAT2* in the mouse.

METHODS AND RESULTS: A prostate specific rat promoter, probasin (-426 to +28, the minimal region required for activation), has been cloned into a modified expression vector and sequenced. Utilizing specific primers we amplified the rat probasin promoter from isolated rat DNA by polymerase chain reaction (PCR). We also engineered this PCR product to contain a 5′ *Sac*I-*Not*I restriction site and a 3′ *Bam*HI restriction site. These restriction sites allowed us to ligate the promoter into our expression vector. Next, we amplified human wildtype *NAT1* and *NAT2* from human DNA by PCR and engineered these products to contain 5′ and 3′ *Eco*RI restriction sites. These products were then ligated into the multiple cloning site of the pKS/RIP vector. Finally, we sequenced our cloned genes to ensure that Taq polymerase did not introduce a base change. We then liberated our transgene constructs by restriction digest with *Not*I and *Xho*I and purified them by agarose gel electrophoresis.

CONCLUSIONS: Two constructs were engineered to contain human *NAT1* and *NAT2* which are under the control of the rat, prostate specific, probasin promoter. The *NAT2* construct has been injected into mouse embryos and implanted into receptive females. A coat color construct was also injected and we have generated offspring which have the coat color phenotype, suggesting that our transgene was successfully integrated into the genome. Further characterization is planned to verify human *NAT2* mRNA and enzyme expression. The *NAT1* construct will be injected into embryos in the near future. Ultimately, these transgenic models will provide useful information on aromatic and heterocyclic amine carcinogen metabolism by prostate-specific human *NAT1* and *NAT2*. They also will be useful for studies to assess the role of acetylation and its genetic polymorphisms in the etiology of prostate cancer.

ACKNOWLEDGEMENTS: This work was partially supported by USPHS grant CA-34627 from the National Cancer Institute.

THE EFFECTS OF INCREASED LEVELS OF CATALASE, METALLOTHIONEIN AND ALCOHOL DEHYDROGENASE IN THE HEART OF TRANSGENIC MICE ON ALCOHOL-INDUCED CARDIAC TOXICITY

Qiangrong Liang* and Paul N. Epstein
Department of Pharmacology and Toxicology, School of Medicine and Health Sciences,
University of North Dakota, Grand Forks, ND 58202

Chronic, excessive consumption of alcohol is a frequent cause of congestive cardiomyopathy. Almost one third of alcoholics exhibit cardiac dysfunction and many develop irreversible alcoholic heart muscle disease (AHMD). In addition to chronic toxicity, alcohol has acute toxic effects on the human and animal heart that are clinically significant. It is possible that AHMD may be due to the accumulation of these acute injuries.

The specific toxic agent that produces AHMD remains a major subject of controversy. Some proposals suggest that ethanol or the nonoxidative product, fatty acid ethyl esters are the direct cardiotoxic agent. However, other hypotheses propose that AHMD is due to acetaldehyde, the major oxidative metabolite of ethanol produced by alcohol dehydrogenase. In addition, lipid radicals have been detected in the heart of rats treated acutely and chronically with alcohol, implicating free radicals in the pathogenesis of alcoholic cardiomyopathy.

We have produced multiple lines of transgenic mice in which either catalase, an antioxidant enzyme or metallothionein (MT), a free radical scavenger have been overexpressed specifically in the heart. These transgenic mice provide valuable models to examine the role of free radicals in ethanol cardiotoxicity. Moreover, we have just produced eight new strains of transgenic mice overexpressing alcohol dehydrogenase (ADH) in the heart. This will allow us to distinguish whether ethanol or a metabolic product of ethanol such as acetaldehyde is the specific cardiotoxic agent.

Using the Langendorff perfused mouse heart we have determined the effect of elevated catalase and MT on alcohol-induced acute cardiotoxicity. In control hearts 0.5g/dl and 1g/dl ethanol inhibited contractility by 27% and 49% respectively. Preliminary results indicated that catalase and MT did not provide protection against the cardiotoxicity induced by alcohol at these concentrations. This result suggests that free radicals are not the major mechanism by which alcohol produces its acute toxic effect on the heart. In the future we will evaluate the role of free radicals in alcohol-induced chronic cardiotoxicity by long term administration of a liquid alcohol diet *in vivo*. We will also test whether transgenic mice with elevated ADH activity are protected from acute and chronic alcohol toxicity.

MITOCHONDRIAL AND CYTOSOLIC ISOENZYMES OF NUCLEOSIDE DIPHOSPHATE KINASE IN PIGEON

James G. Mehus*, Barry I. Milavetz, Mary A. Ivey, and David O. Lambeth
Department of Biochemistry and Molecular Biology, UND School of Medicine, Grand Forks, ND 58202

Nucleoside diphosphate kinase (NDPK) has classically been viewed as a housekeeping enzyme that is ubiquitously present in the cell. Its catalytic activity is important in transferring phosphate from a nucleoside triphosphate donor to a nucleoside diphosphate acceptor ($NDP_A + NTP_B \rightarrow NTP_A + NDP_B$). The NDPK activity present in mitochondria presumably converts GTP produced in the Krebs cycle into ATP. Roles of the cytosolic NDPK enzyme include provision of nucleotide triphosphates for synthesis of nucleic acids, glycogen, and lipids. The NDPK protein also has functions which are apparently unrelated to its catalytic activity (1). In the nucleus, the human NDPK protein (PuF) acts as a transcription factor for the *c-myc* protooncogene. Human NDPK isoforms (Nm23) appear to be involved with metastasis in some tumors. In *Drosophila*, expression of a NDPK homologue (*Awd*) may be necessary for normal embryogenesis. So, we currently view NDPK as a multi functional protein.

Work in our laboratory has focused on the role of NDPK in the mitochondrial matrix. In higher vertebrates, GTP is synthesized in the Krebs cycle via succinate thiokinase. There is no known transporter of GTP/GDP in the mitochondrial membrane system. Therefore, NDPK functional linkage to a GTP-synthesizing succinyl-CoA synthetase seems to be required in order to produce ATP and replenish the GDP pool for continued metabolism. However, in some vertebrate species, fractionation and functional studies do not indicate presence of NDPK in the mitochondrial matrix but rather show NDPK activity in outer membrane or intermembrane space. Submitochondrial compartmentation of NDPK also seems to vary depending on tissue. Genetic analysis of NDPK in several species has so far provided DNA sequences for three or four specific isoenzymes, none of which appear in mitochondrial matrix. The goal of our research is to determine if there are separate genes encoding mitochondrial matrix and cytosolic isoforms, or whether the two proteins are derived from a single gene via alternative processing. We also plan to investigate the tissue distribution of the mitochondrial-specific NDPK.

The experimental organism used for this research is pigeon (*Columbia livia*), because previous studies indicated a very high level of NDPK enzymatic activity in pigeon liver mitochondrial matrix (2). Pigeon also has GTP-specific and ATP-specific succinate thiokinases that are localized to specific tissues. NDPK activity was purified from mitochondrial fractions of pigeon liver. A single band with a molecular weight of about 18 kDa was seen on SDS-PAGE. N-terminal sequencing of the mitochondrial protein yielded an amino acid sequence for the first 20 residues. Samples of mRNA were prepared from the liver tissue via paramagnetic oligo dT beads and oligo dT spin columns. Template cDNA for PCR experiments was prepared by reverse transcription using oligo dT_{17} primers or gene-specific primers where necessary. Initial PCR experiments were performed with degenerate primers derived from protein (N-terminal of mitochondrial protein) and alignment sequences (cytosolic NDPKs). The cloning of PCR products utilized the M13 bacteriophage vector. DNA sequencing was performed by ABI Prism automated sequencing, with confirmation obtained from performing multiple sequencing of both strands. Once large internal sequences were obtained for the cDNAs, 3' and 5' RACE techniques were used to obtain the full-length cDNAs. Semiquantitative RT-PCR with mitochondrial- or cytosolic-specific primers was used to determine relative expression levels of the two isoforms in three tissues.

The full-length cDNA for cytosolic NDPK has a deduced amino acid sequence that is over 90% identical to both human cytosolic NDPKs (nm23-H1 and nm23-H2). The entire cDNA sequence of the mature form of mitochondrial matrix NDPK has also been obtained. No close homologue of this isoform has been found in the gene banks, thus this sequence appears to represent a novel NDPK gene. 5' RACE procedures are currently being employed to obtain the remaining 5' end, including the mitochondrial targeting sequence. This new mitochondrial matrix NDPK cDNA encodes a protein that is only 53% identical with the cytosolic homologue. Including conserved residue substitutions, there is about 70% homology between the two isoenzymes. Semiquantitative RT-PCR using mitochondrial- and cytosolic-specific primers and mRNAs from three pigeon tissues showed that cytosolic NDPK seems to be highly expressed in liver, breast, and especially heart. In contrast, evidence of mitochondrial specific NDPK was found only for liver tissue.

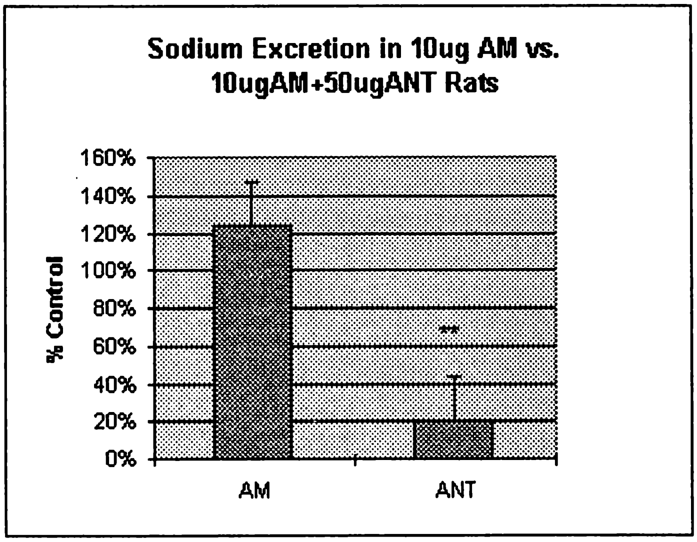
We conclude that a separate gene codes for mitochondrial NDPK. The sequence of this gene is clearly homologous to cytosolic NDPK of pigeon, and to the various eukaryotic and prokaryotic NDPKs entered into genetic databases. However, the sequence identity is low suggesting that divergence of mitochondrial NDPK from the other NDPKs occurred in the distant past. Future work will involve obtaining genomic sequences and over expression of the proteins in a recombinant system. We will seek to extend these studies to higher organisms, including human.

1. DeLaRosa, A., Williams, R.L., and Steeg, P.S. (1995) Bioessays 17:53-62.
2. Muhonen, W.W., and Lambeth, D.O. (1995) Comp. Biochem. Physiol. 110B: 211-223.

PORCINE ADRENOMEDULLIN (26-52) ATTENUATES THE NATRIURETIC RESPONSE TO INFUSED ADRENOMEDULLIN (1-50) IN THE ANESTHETIZED RAT

M. P. Murphy*, W. K. Samson, and R. C. Vari
University of North Dakota School of Medicine and Health Sciences, Grand Forks, ND 58202

Adrenomedullin (AM) is a newly discovered peptide which possesses vasodilatory and natriuretic properties. The *in vivo* mechanisms whereby AM may act to physiologically influence natriuresis are presently undefined. The objective of this study was to determine the effects of co-administered porcine AM (26-52), a putative selective AM receptor antagonist, on the natriuretic response to exogenous AM infusion in the anesthetized rat. Infusion of 10ug rAM for 30 minutes significantly increased ($p < .01$) urinary sodium excretion 124 ± 31% above pre-infusion levels ($U_{Na+}V$, 0.495 ± 0.114 vs. 0.242 ± 0.068 uEq/min; n=7). In rats infused with 50 ug pAM 26-52 prior to and during rAM infusion urinary sodium excretion increased only 20 ± 16% above pre-infusion levels ($U_{Na+}V$, 0.471 ± 0.055 vs. 0.446 ± 0.093 uEq/min; n=6). Mean arterial blood pressure was not changed by infusion of rAM or pAM 26-52 and averaged 119 ± 1 and 127 ± 2 mmHg respectively. Urine flow increased from 4.1 ± 0.5 to 9.0 ± 2.3 ul/min during AM infusion and from 6.0 ± 1.0 to 9.3 ± 0.7 ul/min in the rats co-infused with pAM 26-52. These results indicate that 50 ug porcine AM (26-52) is an effective dose to significantly attenuate the natriuretic effect of exogenously administered AM. Therefore, pAM 26-52 may be a useful pharmacological tool to evaluate the *in vivo* role of AM in the regulation of sodium and blood pressure homeostasis in the rat.



Urinary Sodium Excretion ($U_{Na+}V$) in uEq/min

	Pre-infusion	Post-infusion
10ug rAM	0.242 ± 0.068	0.495 ± 0.114
10ug rAM + 50ug pAM	0.446 ± 0.093	0.471 ± 0.055

COBALT (II) TETRASULFOPHTHALOCYANINE CATALYZED AUTOXIDATION OF PENTAFLUOROTHIOPHENOL

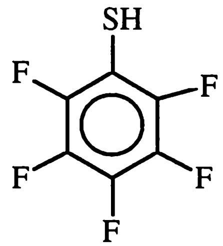
Ali Navid* and Evguenii I. Kozliak
Department of Chemistry, University of North Dakota, Grand Forks, ND 58202

Catalytic oxidation using cobalt tetrasulfophthalocyanine (CoTSPc) is one of the main methods used for deodoration of petroleum products and removal of thiols and other industrial pollutants from waste waters. The process models the reactions of cytochrome P-450 enzymes and thus has biomimetic significance.

$$4RSH + O_2 \xrightarrow{CoTSPc} 2RSSR + 2H_2O$$

Interesting substrates of the above reaction, which have rarely been studied, are acidic thiols and thioacids. CoTSPc is an effective catalyst for oxidation of phenols, olefins, hydrogen sulfide, and other substrates. Acidic thiols can be considered a bridge between thiols and these other substrates of CoTSPc-catalyzed autoxidations, and therefore merit extensive research.

The acidic thiol studied here was pentafluorothiophenol (PFTP) (pK_a=2.68). The substrate and the catalyst were anaerobically combined and binding studies using a UV-Vis spectrophotometer were conducted. Whereas majority of basic thiolates bind to CoTSPc and reduce the cobalt (II) to cobalt (I); PFTP bound to the catalyst forms three types of complexes. In aqueous solutions, dithiolate Co(II)TSPc complexes were detected. The ability of PFTP to form Co(II) dithiolate complexes is unique to this ligand. No thiolate, including any of like acidity forms such stable complexes. We believe that the added stability of cobalt (II) dithiolate complexes formed by this substrate might be attributed to π-stacking of aromatic rings on the ligand. Preliminary studies of 4-fluorothiophenol (4FTP), a thiol of similar aromatic structure to PFTP, have not yielded Co(II) complexes. This could mean that the observed stability might be result of additional factors yet not considered.



pentafluorothiophenol

In aqueous solutions with Triton X-100 surfactant, and potassium ferricyanide as an oxidant, Co(III)TSPc dithiolate complexes were detected. It is worth noting that Co(III) dimercaptide complexes are unstable for basic thiolates; however, our studies show that acidic thiols and thioacids form stable complexes of this kind. These dimercaptide cobalt (III) complexes are a new type of intermediate proposed for the catalytic autoxidation process. By studying these complexes of CoTSPc with thiolates of similar acidity, the role of electron transfer in the proposed intermediates can be elucidated.

Kinetic examination of PFTP autoxidation using an oxygen specific electrode have thus far shown first order kinetics with respect to the concentrations of the catalyst and the substrate. Studies show a first order reaction rate dependence with respect to oxygen in the $1x10^{-4}$ to $2x10^{-4}$ (mol/l) oxygen concentration range. Aliphatic thiols generally exhibit Michaelis-Manten kinetics with respect to oxygen concentration and similar kinetics might be expected for PFTP. Rates of reaction observed for PFTP autoxidations are smaller than those for aliphatic thiols such as cysteine[1]. Thioacids and acidic thiols do not reduce Co(II) to Co(I) and this may account for the observed reduced rates of reaction for these substrates.

1. Navid, A., Kozliak, E. (1997) ACS fuel division preprints, in press.

EXPESSION OF WAF1 IN RAT LYMPHOMA CELLS

Hugh V. Nguyen*, Donna J. Buckley, Arthur R. Buckley
Department of Pharmacology and Toxicology, University of North Dakota School of Medicine, Grand Forks, ND 58202.

Lactogen-dependent, rat pre-T Nb2 lymphoma cell lines have proven to be an exceedingly useful model for investigation of early signaling and molecular events coupled to prolactin (PRL)-stimulated proliferation. In addition, recent evidence has demonstrated the utility of this model for the study of molecular mechanisms which underlie glucocorticoid (dexamethasone, DEX)-activated programmed cell death (apoptosis) in T-lineage cell systems. In this paradigm, PRL deprivation for 18 - 24 hrs arrests growth in the early G1 phase of cell cycle. The addition of picogram quantities of PRL to such stationary cultures, initiates a partially synchronous proliferative response characterized by the expression of several immediate early (1) as well as apoptosis-associated genes (2). Notably, DEX-activated apoptosis in this system is inhibited by PRL treatment. The purpose of the present study was to determine whether DEX-induced apoptosis or its inhibition by PRL in Nb2-11 cells was mediated by WAF1, an inhibitor of cell cycle progression and a demonstrated facilitator of the cell death program in certain systems. Stationary Nb2-11 cells were treated with PRL or PRL + DEX and the expression of WAF1 mRNA and its protein product were evaluated throughout a 24 hr time period. The results indicate that exponentially proliferating Nb2-11 cells expressed significantly higher levels of the WAF1 protein and its mRNA compared to quiescent cultures. However, the addition of PRL to stationary Nb2-11 cells rapidly induced the expression of the WAF1 transcript (2.1 kb) which reached maximal levels within 3 hr. Increased levels of the WAF1 protein followed the accumulation of its mRNA reaching maximal levels (2-fold compared to control) by 8 hr following PRL stimulation. In quiescent cultures treated with PRL+DEX, the WAF1 protein was similarly increased 2-fold within 8 hr whereas its mRNA accumulated through 2 hr after which it remained unchanged throughout the duration of the experiment. In stationary Nb2-11 cultures treated with DEX, both WAF1 protein and its mRNA were decreased to non-detectable levels within 24 hr. These results suggest that DEX-activated apoptosis in Nb2-11 cells most likely does not reflect a contribution by WAF1. Moreover, the observation that PRL significantly enhances WAF1 protein expression within 8 hrs, a time point previously demonstrated to correspond to the late G1 phase of cell cycle (1) is consistent with a regulatory role for this protein in lactogen-stimulated Nb2-11 cell proliferation.

1. Buckley, A. R., Buckley, D.J., Leff, M.A., Hoover, D.S., and Magnuson, N.S. (1995) Endocrinology 136: 5252-5259.
2. Leff, M.A., Buckley, D.J., Krumenacker, J.S., Reed, J.C., Miyashita, T., and Buckley A.R. (1996) Endocrinology 137: 5456-5462.

AIR PURIFICATION IN FIBER BASED TRICKLE-BED BIOREACTORS

Tana L. Ostlie Dunn* and Evguenii I. Kozliak
Department of Chemistry, University of North Dakota, Grand Forks, ND 58201

Biological air purification methods may remove organic pollutants from the air at a fraction of the cost of more traditional methods. With only CO_2 and water as by-products, select bacteria have the ability to degrade toxic organic compounds. These chemical-specific bacteria may be cultured to use the toxic organic compounds as nutritional carbon sources. Trickle-bed bioreactors immobilize bacteria on filter material within the reactor. Water, supplied with some dissolved salts, is trickled over the filter to provide the bacteria with sufficient inorganic nutrients. This procedure supplies water to the microorganisms without complete suspension of the bacteria within the water.

Pollutant solubility in water, oxygen availability throughout the filter, and biological degradation rates are the limiting factors of trickle-bed bioreactors as determined in previous studies [e.g. Investigated by Kirchner (1,2,)]. The use of chemical fibers as supports for immobilization of bacteria in trickle-bed bioreactors is suggested in this study.

Various fibrous filters are being investigated using two different strains of bacteria in this study. The first bacterial strain, *Pseudomonas fluorescens, Sty*, was cultured to grow on styrene. Styrene was believed to be recalcitrant in the earliest studies of bioremediation. However, preliminary results of this study show styrene degradation of up to 60%. The other bacteria strain, referred to as WOD-T, was cultured to grow on toluene.

With air-flow velocities of 2400 h^{-1} and inlet concentrations of 100 to 500 mg/m^3, the efficiency degradation rates 60-100% for ethyl acetate, toluene, styrene, and m-xylene have been achieved. These parameters are within the range of chemical air purification methods and greater than those of other biological methods. Trickle-bed bioreactors using fibrous filter material exhibit higher activity than those using granular filter materials (1,2).

The pressure drop of the system is also reduced when using fiber material. Preliminary calculations of the amount of biomass per filter have given approximately 2 grams of live biomass per 1 gram of filter. This increase in the amount of biomass is achieved without increasing the pressure drop of the system. If the biological degradation is the rate determining step, increasing the amount of biomass in the filter is essential to increase the efficiency of the reactor.

It has always been suggested that a pollutant must first be absorbed into an aqueous phase before bacteria can utilize it as a nutritional carbon source. The higher efficiency of fiber-based trickle-bed bioreactors compared to known analogs (1,2) may be explained by the physical features of the fiber. Fibers have a higher surface area for the immobilization of bacteria and more biomass per filter is achieved. The use of fibers improves the mass transfer on the biocatalyst of the bioreactor system The increased surface area of the filter provides a higher contact area so that the chemical compound is more likely to interact with the aqueous phase. In addition, air flow passes through the system freely, ensuring that oxygen levels throughout the entire filter are more consistent.

1. Kirchner, K., Schlachter, U., Rehm, H.-J., (1989) Appl Microbiol Biotechnol 31: 629-632.
2. Kirchner, K., Wagner, S., Rehm, H.-J., (1992) Appl Microbiol Biotechnol 37: 277-279.

ULTRASTRUCTURAL AND FUNCTIONAL ANALYSES OF NEPHROPATHY IN THE SPONTANEOUSLY DIABETIC BB/WISTAR RAT

Michael J. Ressler*, and Edward C. Carlson
Department of Anatomy and Cell Biology
School of Medicine and Health Sciences, University of North Dakota
Grand Forks, North Dakota 58202

Various animal models have been utilized in the study of diabetic nephropathy. In most of these the cause of the disease is either unknown or is induced by chemical toxins. The BB/Wistar rat is a model of insulin-dependent diabetes mellitus which is genetically predisposed to develop the disease as a result of autoimmune destruction of pancreatic beta-cells with resultant hypoinsulinemia and hyperglycemia. In the current study, several structural alterations in the renal glomerular extracellular matrices (ECMs) in the spontaneously diabetic BB/Wistar rat are examined and related to parameters (urine glucose and protein concentrations) of renal function.

Renal cortical tissues were collected from normal and diabetic rats at two weeks, three months, six months, and one year post-onset of hyperglycemia. The rats were maintained under moderately hyperglycemic (300 +/- 50 mg/dl) conditions with the aid of the "Limplant" sustained release insulin implant system. Some of the tissues were used for light microscopic examination. Those tissues were stained with hemotoxylin and eosin, periodic acid Schiff, or Jones silver to facilitate visualization of various components of the tissue including glycoproteins and other carbohydrates. Additional cortical tissue was prepared for and examined by conventional transmission electron microscopy. Some tissues were processed by a modification of the detergent extraction method defined by Carlson and coworkers (1) which disrupts and removes the cells leaving behind intact ECMs including glomerular basement membranes (GBMs) and mesangial matrix (MM). Morphometric analysis of transmission electron micrographs of acellular GBM thickness was carried out by a modification of the "orthogonal intercept" method (2). Acellular tissues were also visualized by scanning electron microscopy to evaluate the three dimensional morphology of the MM. The remaining renal tissues were stained with polyethyleneimine (a cationic stain) which labels anionic sites (AS) located in the GBM and other ECMs by a modification of the method of Schurer and associates (3). Finally, 24 hour urine samples were collected from fasted animals and protein concentrations were determined in these samples.

Data in the current study indicate that diabetic BB/Wistar rats develop renal hypertrophy and show significant increases in GBM thickness three months to one year post-onset of hyperglycemia when compared with age-matched controls. Light microscopic examination of Jones silver and periodic acid Schiff stained glomeruli shows that at three and six months post-onset of hyperglycemia a slight increase in carbohydrate-rich material is associated with the GBM of peripheral capillary loops. At one year, a moderate increase in carbohydrate-rich material is seen in the mesangial region and peripheral GBM when compared with age-matched controls. This correlates with increased renal ECM components as imaged by scanning electron microscopy. Furthermore, transmission electron microscopic investigations show that polyethyleneimine-positive GBM AS integrity is unchanged in both diabetic and control rats.

In summary, it was concluded from these studies that one year of moderate hyperglycemia in diabetic rats resulted in altered kidney sizes, MM morphology, and GBM thicknesses. However, these rats did not develop an otherwise expected proteinuria and their GBM AS profile was similar to that observed in control rats. Accordingly, the present study shows that despite the large number of morphological indictors of chronic diabetes in the moderately hyperglycemic BB-rat model, two features remain unchanged—normal AS densities and normal urinary protein. It seems possible, therefore, that the BB-rat may be an appropriate model for future studies in which the chronic effects of glucose toxicity on renal structure and function may be examined. This could include careful permeability studies and molecular analyses of renal ECMs isolated from this model. It would be hoped that such studies may lead to a new understanding of the mechanisms of diabetic nephropathy and the associated devastating renal dysfunction.

1. Carlson, E.C, K. Brendel, J.T. Hjelle, and E. Meezan (1978) J. Ultrastruct. Res., 62:26-53.
2. Jensen, E.B., H.J.G. Gundersen, and R. Osterby (1979) J.Microscopy, 115:19-33.
3. Schurer, J.W., D. Kalicharan, P.J. Hoedenmaker, and I. Molenaar (1978) J. Histochem. Cytochem., 26:688-689.

BOREHOLE TEMPERATURE HISTORY IN THE NORTHERN PLAINS

William L. Schmidt * and William D. Gosnold
Department of Geology and Geological Engineering, University of North Dakota, Grand Forks, ND 58202

An understanding of air-ground temperature coupling is critical to any borehole climate change study. The upper 200-300 meters of the Earth's crust records long-term changes in the Ground Surface Temperature (GST). Daily and yearly temperature fluctuations are filtered out in the upper 20-30 meters, while century-long changes are propagated further into the crust. Boreholes in the crust allow measurement of the geothermal gradient of a location. A least-squares inversion of this temperature gradient determines the historical GST of the borehole. Borehole studies of climate change have always assumed a complete 1:1 tracking of air-ground temperatures at the surface of the borehole. The complex linkage between GST and Surface Air Temperature (SAT) is imperfectly known.

Models of global warming based on the doubling of CO_2 in the atmosphere predict a northerly temperature increase in the mid-continent region of North America (1). Ground warming per century along a 1000 km transect of the Northern Plains region containing 28 selected boreholes has averaged 1.4°C and increases from 0.6°C to 2.5°C between 42°N and 49.5°N. Air temperature data from the Historical Climate Network (HCN) was analyzed. A linear regression of annual mean temperatures allows determination of SAT change per century at each HCN site in the region. A regression of the SAT change per century yielded an increase of 0.95°C in the range 40°-48°N. The discrepancy in long-term temperature change between the borehole record and historical air temperature record is greatest in areas of seasonal ground freezing and snow cover. Seasonal snow cover insulates the ground from low air temperatures, and latent heat released by the freezing of soil moisture holds soil temperatures at the freezing point until all water present has frozen (2).

Three boreholes were drilled within 40 km of an HCN site in North Dakota, South Dakota, and Nebraska. Hypothetical borehole temperature profiles were created that correspond to the time of origin of SAT records at each HCN site. Historical air temperature records exist from 1900-1994. Annual mean air temperature is the forcing function for the hypothetical profile in this forward model. Thermal conductivity of the modeled subsurface is 1.2 W/m*K. The 1994 profile generated for each of the HCN sites was inverted to determine the GST history. A regression of the GST change from the generation of synthetic profiles at all HCN sites in this region produced a temperature increase of 0.163°C per degree latitude in the range 40°-48°N. This 1-dimensional conduction model assumes a 1:1 tracking of air and ground temperatures, and does not incorporate snow cover insulation or latent heat released by freezing of soil moisture. Discrepancies in long term temperature change can be due to microclimatic effects between the borehole location and HCN site.

1. Hansen, J.E., Fung, I., Lacis, A., Rind, D., Lebedeff, S., Ruedy, R., Russel, P., and Stone, P., (1988) J. Geophys. Res., 93, 9341-9364.
2. Lewis, T.J, and Wang, K., (1992) Palaeogeog., Palaeoclim., Palaeoecol., (Global and Planetary Change Section) 98: 87-100.

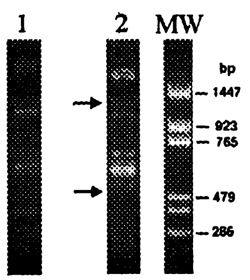
RAPD PCR ANALYSIS OF CRYPTOSPORIDIUM ISOLATES IN THE UPPER MIDWEST

Kevin Shianna* and Jon Spanier
Department of Microbiology and Immunology
University of North Dakota, Grand Forks, North Dakota 58202

PURPOSE: *Cryptosporidium parvum*, a protozoan parasite, is the agent that causes bovine Cryptosporidiosis in newborn calves. This disease results in severe diarrhea, thus leading to dehydration. If untreated a calf will usually die. C. *parvum* infections in calves result in losses of millions of dollars annually. The infectious form of the organism is the oocyst, which is passed in the feces and remains stable in the environment for many months. We are typing bovine strains of Cryptosporidium using Random Amplified Polymorphic DNA Polymerase Chain Reaction (RAPD PCR) with the expectation that more virulent strains will produce a DNA fingerprint that is distinct from less virulent strains and ultimately help identify specific proteins linked to virulence.

METHODS: In this study, calf fecal samples from throughout North Dakota and Minnesota were collected by veterinarians and sent to the North Dakota State University Veterinary Diagnostic Lab where these samples were tested for many organisms. Any samples that were positive for C. *parvum* were saved and given to us. Once we received the positive fecal samples, the oocysts were purified away from the fecal material during two sequential gradients: Sheather's sucrose (1) and cesium chloride (CsCl) (2). The Sheather's sucrose gradient consisted of two 20 ml steps with specific gravities of 1.064g/L and 1.103g/L. Approximately 10 ml of homogenized feces was layered on top of the discontinuous gradient. The sample was then spun at 2,000xg for 30 minutes. After the spin, 10-15 ml of the gradient was taken above the 1.103g/L step and washed three times. The sample was resuspended in 1 ml of dH_2O once the last wash was completed. The Sheather's purified sample was then layered on top of a CsCl gradient which consisted of three steps (1.05, 1.1 and 1.4 g/ml). The gradient was spun at 16,000xg for one hour. Once the spin was complete a one ml sample was collected with a syringe above the 1.1 g/ml step (band was usually visible). The sample was then washed as before. The purity of the oocysts was determined by light microscopy (400X) and PCR using primers from likely contaminants. The DNA was released from the oocysts during six freeze/thaw cycles using a dry ice/ethanol bath and a heating block set at 98°C and then used in RAPD PCR. The RAPD PCR was run under the following conditions: 1 minute at 94°C, 1 minute at 37°C, 2 minutes at 72°C for 37 cycles followed by a 9-minute hold at 72°C. After the reaction was complete, one-tenth of each sample was run on a 1.5% agarose gel. The addition of ethidium bromide to the gel allowed for visualization of the DNA products.

RESULTS AND DISCUSSION: RAPD PCR utilizes one primer under non stringent annealing conditions. Therefore, for a product to be amplified exponentially the primer has to anneal to opposite strands within a few thousand base pairs of one another. If only one primer binds, linear amplification occurs and the fragment isn't amplified enough to be seen on an agarose gel with ethidium bromide. RAPD PCR is done under non-stringent conditions so the individual primer only needs partial homology to bind to the template DNA. These factors allow for a DNA fingerprint of each isolate by creating a set of PCR products. Only isolates that are genetically identical will give the same pattern. Using RAPD PCR, we amplified 25 unique isolates with 4 different primers and separated the resulting products by electrophoresis. Strain differences were evident between the isolates. The figure shows an example of some differences for one primer (arrows indicate differences between the two strains). We determined similarity coefficients (3) between each pair of strains to more precisely measure the differences between them; and we will discuss our findings.



CONCLUSIONS: There are numerous genetic differences between Cryptosporidium strains throughout the states of North Dakota and Minnesota.

1. Arrowood, M.J., and Sterling, C.R. (1987) Isolation of Cryptosporidium oocysts and sporozoites using discontinuous sucrose and isopycnic Percoll gradients. J-Parasitol 73, 314-9.
2. Kilani, R.T., and Sekla, L. (1987) Purification of Cryptosporidium oocysts and sporozoites by cesium chloride and Percoll gradients. Am-J-Trop-Med-Hyg 36, 505-8.
3. Morgan, U.M., Constantine, C.C., Greene, W.K., and Thompson, R.C. (1993) RAPD (random amplified polymorphic DNA) analysis of Giardia DNA and correlation with isoenzyme data. Trans-R-Soc-Trop-Med-Hyg 87, 702-5.

HEAT SHOCK FACTOR PROTEOLYSIS AND APOPTOSIS IN Nb2-LYMPHOMA CELL: PROTECTIVE EFFECTS OF PROLACTIN

Mingyu Zhang*, Michael J. Blake, Donna J. Buckley, and Arthur R. Buckley
Department of Pharmacology and Toxicology, University of North Dakota School of Medicine
Grand Forks, ND 58202.

Previously, we have shown that Nb2 lymphoma cells have an aberrant heat shock response due to the selective proteolysis of heat shock transcription factor (HSF) by cysteine proteases. Furthermore, preincubation of stationary Nb2 cells with prolactin (PRL) attenuated heat-induced HSF proteolysis in a time-dependent manner. Specific proteases are believed to be major contributors to the process of apoptosis. Interestingly, Nb2-11 cells are particularly sensitive to apoptotic agents, a property that may reflect their hormone-dependent phenotype and contribute to possible treatment strategies for this class of neoplasms. In this study, we have investigated whether HSF is a specific target for activated proteases in cells undergoing apoptosis. Apoptosis was invoked by heat shock (41°C, 1 hr) in both PRL-dependent Nb2-11 cells and in a hormone-independent subline (Nb2-SFJCD1) as determined by DNA fragmentation on agarose gels and flow cytometry. Consistent with previous work, PRL blocked heat-induced HSF proteolysis and concomitantly reduced both the percentage of apoptotic cells and DNA fragmentation. To determine the specificity of this relationship, Nb2 cells were treated with other apoptogenic agents. Vinblastine, cycloheximide, and thapsigargin were all potent simulators of HSF proteolysis and apoptosis in both cell lines. PRL protected cells from the apoptotic effects of vinblastine but was ineffective in cells treated with either cycloheximide or thapsigargin. Importantly, iodoacetamide, a cysteine protease inhibitor that blocks HSF fragmentation, was also an effective inhibitor of apoptosis. Collectively, these data reveal a strong relationship between the proteolysis of HSF and apoptosis. HSF proteolysis and the concurrent loss of an appropriate heat shock response appear to contribute significantly to apoptotic mechanisms in these cells. Further investigation of the mechanisms responsible for the reversal of these processes by PRL should provide important insights into possible treatment strategies for hormone-dependent tumors and the role of PRL in normal immune cell function.

COMMUNICATIONS

PROFESSIONAL

DIETARY BORON INCREASES SERUM ANTIBODY (IgG and IgM) CONCENTRATIONS IN RATS IMMUNIZED WITH HUMAN TYPHOID VACCINE

Yisheng Bai, Curtiss D. Hunt, and Samuel M. Newman, Jr.*
USDA, ARS, Human Nutrition Research Center, Grand Forks, ND 58202

We previously reported that supplemental dietary boron (SDB) added to low-boron diets increased serum antibody (IgG) concentrations in rats vaccinated with heat-killed *Mycobacterium tuberculosis* (1), and increased total antibody titers in chicks injected with sheep red blood cells (2). This study ascertained whether boron intake affects antibody concentrations in rats vaccinated with human typhoid vaccine. Weanling male Sprague-Dawley rats were fed a low-boron basal diet (~ 0.15 mg boron/kg) supplemented with 0 (0B) or 1.75 (1.75B) mg boron/kg (10 rats/treatment) for 44 d. Rats were vaccinated (s.c.) at d 14 of the study. An additional 10 rats were fed the basal diet but not vaccinated; they served as controls (Control). Immediately before, and at 1, 6, 10, 20, and 30 d following vaccination, blood was drawn from the tail artery of rats anaesthetized with ether. Serum was collected and stored at -25° C until analyzed for antibodies. Total serum anti-typhoid antibody (IgM and IgG) concentrations were determined by using an established ELISA method in which goat anti-rat IgM or IgG (H+L) polyclonal antibody conjugated with horseradish peroxidase (2000x dilutions) was used. Serum samples were diluted 100x for IgM and 2500x for IgG determinations (based on preliminary test results) and loaded to wells pre-coated with sonicated typhoid vaccine. Optical density of the enzymatic reaction was determined at a wavelength of 490 nm and expressed as OD490. Student's t-test was used to compare treatment differences (0B vs. 1.75B).

Results show that rats, injected with typhoid vaccine, produced anti-typhoid antibody (IgM) 6 d after vaccination; serum antibody concentrations declined slowly thereafter (Fig. 1). SDB slowed the decline of serum anti-typhoid antibody (IgM) concentrations because rats fed SDB, compared to those fed the basal diet, exhibited higher serum anti-typhoid

Fig. 1 Serum IgM concentrations

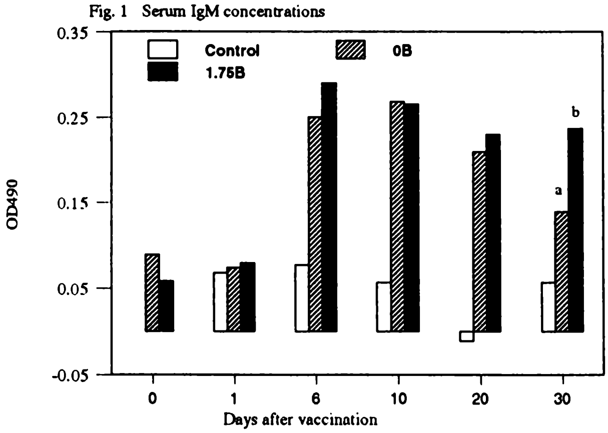
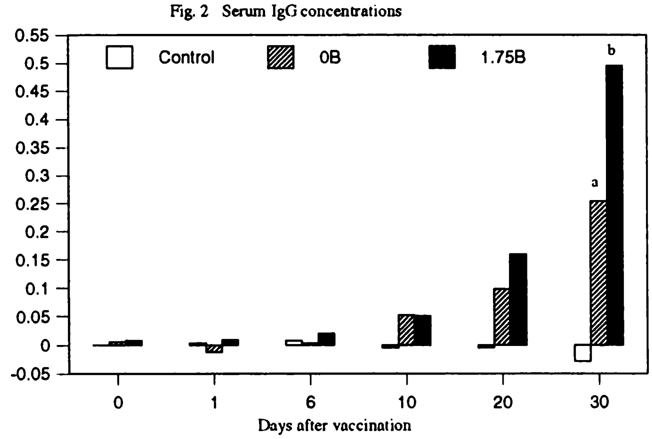


Fig. 2 Serum IgG concentrations



antibody (IgM) concentrations 30 d after vaccination ($P < 0.05$; Fig. 1) . Serum anti-typhoid antibody (IgG) concentrations increased 20 d after vaccination and rose further 30 d after vaccination (Fig. 2). Rats fed SDB, compared to those fed the basal diet, exhibited higher serum anti-typhoid (IgG) concentrations at 30 d after vaccination ($P < 0.05$; Fig 2); this indicates that supplemental dietary boron enhances the IgG response to typhoid vaccine. These observed phenomena were probably not artifactual because they are consistent with our previous findings that dietary boron increased antibody concentrations in animals vaccinated with other antigens during the same phase examined here (1,2). These findings suggest that dietary boron, at concentrations similar to the daily boron intake of humans consuming typical western diets, can influence the immune response in a positive manner and imply that low boron status may diminish immune function.

1. Bai, Y., and C.D. Hunt. 1996. FASEB J 10(3):A819.
2. Bai, Y., and C.D. Hunt. 1996. J Bone and Min Res 11(Supl.):S320.

U.S. Department of Agriculture, Agricultural Research Service, Northern Plains Area is an equal opportunity/affirmative action employer and all agency services are available without discrimination.

EFFECT OF THE ADENOSINE A1 RECEPTOR AGONIST CHA ON RELEASE OF [^{3}H]FORMYCIN B FROM DDT$_1$ MF-2 SMOOTH MUSCLE CELLS

Stephanie L. Borgland*, Wei Xiong, and Fiona E. Parkinson.
Department of Pharmacology and Therapeutics, University of Manitoba, Winnipeg, CANADA.

Adenosine, the dephosporylated breakdown product of ATP, is an autocoid that is released from cells during conditions of metabolic stress. Following release into the extracellular environment, adenosine can bind to adenosine receptors, of which four subtypes have been characterized and cloned. This study was performed to test whether adenosine receptor activation has a feedback effect on the adenosine release process. We used smooth muscle DDT$_1$ MF-2 cells which possess adenosine transporters that are sensitive to inhibition by nitrobenzylthioinosine (NBMPR) as well as both A1 and A2 adenosine receptors. Cells were loaded with [^{3}H]formycin B, a metabolically stable nucleoside analog that is a permeant for the adenosine transporters in DDT$_1$ MF-2 cells. After removing extracellular [^{3}H]formycin B, release was stimulated by resuspending cells in buffer alone or buffer containing 10 µM NBMPR, 30 µM CHA, a selective A1 receptor agonist, or 30 µM NECA, an A1/A2 mixed agonist. Release was inhibited 43% at 22°C and 37% at 37°C by NBMPR and 41% at 22°C and 20% at 37°C by CHA. NECA had no effect on [^{3}H]formycin B release (Fig. 1). The concentration-dependent inhibition of [^{3}H]formycin B release by CHA was examined using concentrations of 0.1µM to 30 µM CHA and IC$_{50}$ values of 3 µM (22°C) and 6 µM (37°C) were obtained (Fig. 2). To test whether this inhibition of release was due to stimulation of A1 receptors, the effect of the selective A1 receptor antagonist DPCPX was investigated. DPCPX (10 µM) had no effect on release by itself and did not block the effect of CHA (Fig.3). To evaluate whether CHA was affecting [^{3}H]formycin B release directly, via an interaction with the transport process, competion binding assays with [^{3}H]NBMPR were performed. CHA produced a concentration-dependent inhibition of [^{3}H]NBMPR binding to DDT$_1$ MF-2 cells and an IC$_{50}$ of 9 µM was obtained (Fig.4).

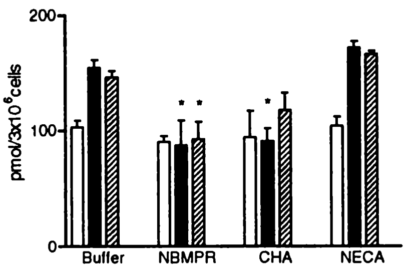


Fig. 1. Release of [^{3}H]formycin B in the presence of 10µM NBMPR, 30µM CHA, or 30µM NECA at 0°C (open bars), 22°C (closed bars), and 37°C (hatched bars). Bars represent S.E.M. of 3 experiments. (* p<0.05).

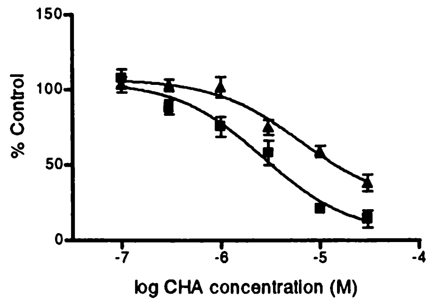


Fig. 2. Inhibition of 10 µM [^{3}H]formycin B release by CHA at 22°C (squares) and 37°C (triangles). Symbols represent means and bars represent S.E.M. of 4 experiments.

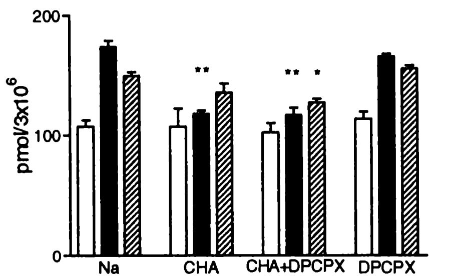


Fig. 3. Release of [^{3}H]formycin B in the presence of 30 µM CHA, 30 µM CHA with 10 µM DPCPX or 10 µM DPCPX at 0°C (open bars), 22°C (closed bars), and 37°C (hatched bars). Bars represent S.E.M. of 4 experiments. (**p<0.001, *p<0 05).

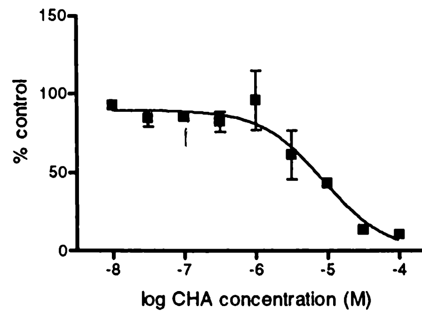


Fig. 4. Concentration-dependent inhibition of [^{3}H]NBMPR binding by CHA.Symbols represent means and bars represent S.E.M. of 2 experiments.

In summary, the adenosine A1 agonist CHA inhibited the cellular release of [^{3}H]formycin B; however this release was not blocked by the A1 receptor antagonist DPCPX. Since CHA inhibited [^{3}H]NBMPR binding to adenosine transporters at concentrations similar to those that inhibited [^{3}H]formycin B release, we conclude that CHA inhibited [^{3}H]formycin B release via a direct interaction with the transport process and not by a receptor-mediated interaction.

STUDIES ON THE MECHANISM OF AMANTADINE ACETYLATION.

Alvaro Bras* and Daniel S. Sitar
Clinical Pharmacology Section and Department of Pharmacology and Therapeutics,
University of Manitoba, Winnipeg, Manitoba R3E 0W3.

A preliminary report indicated that a minor fraction of an amantadine dose is acetylated and excreted in urine (1). Initial studies from our laboratory demonstrated that sulfapyridine-determined acetylator (NAT) phenotype, a marker for NAT-2 activity, did not predict amantadine acetylation in humans (2). We are currently investigating whether the enzymes NAT-1 and NAT-2 contribute to acetylation of amantadine. Liver was obtained from male Sprague-Dawley rats. The tissue was minced, homogenized and the 100,000 x g supernatant was separated by differential centrifugation to isolate acetyl-coenzyme A-dependent N-acetyltransferases (3). p-Aminobenzoic acid (PABA) and sulfamethazine (SMZ) were used as substrate markers for NAT-1 and NAT-2 activity, respectively, for initial kinetic studies. Inhibition studies in the presence of amantadine were also completed. Apparent Km for PABA acetylation by rat enzyme in the absence (245 ± 6 μM), and presence of amantadine (234 ± 13 μM) was not different (mean ± SE, n=4). Vmax 0.45 ± 0.01 vs. 0.42 ± 0.01 nmol/mg protein/min in the absence and presence of amantadine respectively also did not change. Rat liver enzyme was capable of acetylation of SMZ, but the Km and Vmax values were consistent with acetylation by NAT-1 (4), and was not inhibited by the presence of amantadine. Apparent Km for SMZ acetylation by rat liver supernatant was 5824 ± 913 μM and 5666 ± 285 μM (n=4) in the absence and presence of amantadine, respectively. Vmax values for this reaction were 2.11 ± 0.24 and 1.96 ± 0.11 nmol/mg protein/min respectively in the absence and presence of amantadine. Thus amantadine did not affect SMZ acetylation under these experimental conditions. Studies are under way with rabbit liver supernatant to determine whether these observations are species specific. In conclusion, *in vitro* studies with a rat NAT enzyme source and human *in vivo* studies with an NAT-2 phenotyped human subject group support our working hypothesis that there may be an acetyltransferase enzyme other than NAT-1 and NAT-2 which accounts for amantadine acetylation.

1. Köppel, C. and Tenczer, J. (1985) Biomed. Mass Spectrom. 12, 499.
2. Sitar, D.S., Hoff, H.R. and Aoki F.Y. (1991) Clin. Pharmacol. Ther. 49, 156.
3. Grant, D.M., Morike, K., Eichelbaum, M. and Meyer U.A. (1990) J. Clin. Invest. 85, 968.
4. Grant, D.M., Blum, M., Beer, M. and Meyer, U.A. (1991) Mol. Pharmacol. 39, 184.

ULTRASTRUCTURAL MORPHOMETRY OF RETINAL CAPILLARY, PULMONARY CAPILLARY AND RENAL GLOMERULAR BASEMENT MEMBRANE IN TRANSGENIC DIABETIC MICE

Edward C. Carlson*, Janice L. Audette and Paul N. Epstein
Departments of Anatomy and Cell Biology, and Pharmacology and Toxicology
School of Medicine and Health Sciences, University of North Dakota
Grand Forks, North Dakota 58202

OV26 mice are a transgenic diabetic line that overexpress calmodulin in pancreatic beta cells (1). They present many characteristics that make them a particularly valuable, reproducible, and well-defined model of diabetes and diabetic complications. We recently carried out an extensive analysis of the nephropathic structural and functional changes seen in these mice and showed that although they exhibit many of the features of diabetic kidney disease, including nodular glomerulosclerosis and glomerular basement membrane (GBM) thickening, they did not become significantly proteinuric (2).

The current study was undertaken to extend the above mentioned work to other tissues. Since we had shown significant GBM thickening (beyond normal age-related thickening) in our transgenic model, we examined basement membrane widths in two additional sites which, like the GBM, have cells covering both basement membrane surfaces. These included subendothelial basement membranes in retinal capillaries and pulmonary capillary basement membranes.

Three normal and three calmodulin-induced diabetic transgenic mice (300 days of age) were perfused with cold saline followed by cold Karnovsky's paraformaldehyde/glutaraldehyde fixative (3). Renal, retinal and pulmonary tissues were harvested and conventionally prepared for transmission electron microscopy. At least 60 micrographs (15,000 diameters original magnification) of each tissue, from each animal were printed at identical enlarger settings with a transparent sampling grid consisting of 63 squares (3cm x 3cm) superimposed on the print. True basement membrane widths were determined by the orthogonal intercept method (4). Wherever basement membranes intersected with the sampling grid, measurements were taken using a digitizing tablet and computer program (Bioquant, R and M Biometrics, Inc.) designed to place the measurements into one of nine classes of increasing length. Harmonic means of the measurements (> 3,000/ tissue) were calculated and multiplied by $8/3\pi$ (5) to yield true basement membrane thicknesses.

Data in the current study showed that GBM thicknesses in transgenic diabetic mice were increased by ~30% over controls. Interestingly, retinal capillary basement membranes in diabetic animals (also transgenically marked by microphthalmia) were thickened by more than 43%, while pulmonary capillary basement membranes showed only a 1.3% increase. These results suggest that transgene-related increases in microvessel basement membrane thicknesses in several tissues are widely disparate. Moreover, several early signs of the renal/retinal syndrome of human diabetes mellitus appear to be expressed, strongly supporting the utility of the model for future investigations of diabetic retinopathy as well as nephropathy.

1. Epstein, P.N., P.A. Overbeek, and A.R. Means (1989) Cell, 58:1067-1073.
2. Carlson, E.C., J.L. Audette, L.M. Klevay, H. Nguyen, and P.N. Epstein (1997) Anatomical Record, 247:9-19.
3. Karnovsky, M.J. (1965) Journal of Cell Biology, 27:137A-138A.
4. Jensen, E.B., H.J.G. Gundersen, and R. Osterby (1979) Journal of Microscopy, 115:19-33.
5. Gundersen, H.J.G. and R. Osterby (1972) Journal of Microscopy, 97:293-299.

MULTIPLE TRACE ELEMENTS IN HAIR OF ONE MAN OVER TWO DECADES: METHODOLOGY

Dale M. Christopherson*, Terrence R. Shuler, and Leslie M. Klevay
USDA, ARS, Grand Forks Human Nutrition Research Center, Grand Forks, ND 58202

Chemical elements often are measured in hair samples with the hope of obtaining useful clinical, epidemiologic, forensic, nutritional or toxicologic information (1). Analytical methods are sufficiently accurate and precise; medical utility remains largely unproven because of insufficient clinical validation and ignorance of potential variability. The subject of this study used two brands of shampoo low in copper and zinc and collected occiptonuchal hair samples with regularity between February, 1968 and December, 1986. No unusual occupational exposures to chemical elements occurred. Samples (250-300 mg) were extracted with acetone and ether, washed with sodium lauryl sulfate and demineralized water, dried over $CaSO_4$(2) and digested with sub-boiling HNO_3 and clean-room grade hydrogen peroxide. Low temperature digestion in Teflon tubes (140°) minimized sample loss, and contamination from glass tubes (3). The following elements were measured simultaneously by inductively coupled plasma spectroscopy (Leeman[1] PS 5): Calcium, Copper, Iron, Potassium, Magnesium, Manganese, Sodium, Phosphorus, Zinc; and these, sequentially: Aluminum, Boron, Beryllium, Cadmium, Cobalt, Chromium, Nickel, Silicon, Vanadium. Analytical sensitivity for elements measured simultaneously was optimized with manganese. Atomic absorption spectroscopy was used to determine five elements: Arsenic, Mercury, Lead, Selenium and Tin as hydrides, which minimized sample loss and improved sensitivity. Analyses of subject hair were done in random order so that seasonal variation and time trends could be sought. Replicate analyses were done on blanks and various pooled hair samples prepared similarly to the samples of subject hair. Pools, although less homogeneous than samples, digested completely under the conditions employed. Coefficients of variation for the pools ranged from 4% for Zn to 34% for Al. The trace element values presented in this paper are similar to published values (4). Usually several trace elements are measured in a single sample of hair; the within person variability found here reveals that a single analysis may be inadequate for diagnostic purposes or status assessment. Medical intervention based on a single analysis probably is undesirable without supporting data. Neither seasonal effects nor time trends have been found so far; evaluation of data on other elements is in progress with the hope of better defining biological variability. Approximately 100 more samples are available for analysis.

Mean (S.D) Trace Elements in Subject Hair and Hair pools (μg/g)

	Hair Pool No. 1, n=6	Hair Pool No. 2, n=3	Subject , n=20
Copper	7.6 (0.5)	11.5 (.5)	17.7 (14.4)
Zinc	150 (6)	180 (7)	170 (18)
Cadmium	0.008 (0.02)	0.580 (0.13)	0.185 (0.152)
Lead	22.6 (1.6) (n = 3)	3.7 (0.7)	19.7 (27.1)

1. Klevay L.M., Bistrian B.R., Fleming C.R., Neumann C.G. (1987) Amer J Clin Nutr 46, 233.
2. Klevay L.M. (1970) Amer J Clin Nutr 23, 284.
3. Hunt C., Shuler T. (1989) J Micronutrient Anal 6, 161.
4. Chittleborough G. (1980) Sci Total Environ 14, 55.

[1]Mention of a trademark or proprietary product does not constitute a guarantee of warranty of the product by the United States Department of Agriculture and does not imply its approval to the exclusion of other products that may also be suitable.

ORIGIN AND AGE OF SOUTHEAST ALBERTA, SOUTHWEST SASKATCHEWAN, AND NORTHEAST MONTANA HIGH-LEVEL ALLUVIAL DEPOSITS

Eric N. Clausen
Midcontinent Institute, Minot State University, Minot, ND 58707

Southeast Alberta, southwest Saskatchewan, and northeast Montana high-level alluvial deposits cap the Cypress Hills, Flaxville, and other uplands. Previous workers have used paleontologic evidence to assign late Eocene, early Oligocene, and Miocene ages to Cypress Hills alluvium (1), Miocene ages to Flaxville alluvium (1), and Pleistocene ages to some regional valleys-a geologic history which has been interpreted as spanning 45 million years (2). Yet, the Cypress Hills, Flaxville, and similar alluvial deposits and all adjacent valleys and other major landforms can be explained by a continuous progression of events resulting from rapid meltdown of North America's only Cenozoic continental ice sheet and a single meltwater flow route, named here the Alsask River.

Description of Alsask River: The Alsask River was one of several meltwater flow routes which developed during Great Divide River dismemberment (3). During this meltdown Alsask River water flowed south and west from the northern Alberta ice sheet margin into the rising Rocky Mountains and, after flowing southeast through mountain valleys (east of the present-day continental divide), turned to flow east, across southern Alberta and northern Montana, to southwest Saskatchewan and back across the ice sheet margin to join the previously-described supraglacial Midcontinent River (3). Rocky Mountain uplift, which occurred as the meltdown progressed, progressively altered Alsask River routes until all Alsask River flow was east of the rising mountain front. Alsask River dismemberment occurred when ice sheet melting opened up northern drainage routes.

Alsask River evidence: Alsask River existence is documented by major valleys, such as Alberta's Peace, Smoky, Athabasca, Brazeau, and North Saskatchewan valleys, which lead south and west from northern Alberta into the Rocky Mountains and which are linked to an anastomosing complex of northwest-southeast oriented Rocky Mountain valleys (e.g. through valley from Jasper to Banff) which are in turn linked to east-west Rocky Mountain valleys (e.g. Bow River Valley) which point directly toward coarse-grained Rocky Mountain-derived alluvium capping the Cypress Hills, Flaxville, and other uplands in southeast Alberta, southwest Saskatchewan, and northeast Montana. Further, both north and south of the high-level alluvial deposits, the previously-described Southwest Moraine (3) is cut by the Medicine Lake Valley in northeast Montana and the Tyner Valley in Saskatchewan-providing additional evidence large volumes of water flowed east.

Alsask River History: The Cypress Hills alluvial deposits were deposited first as the Alsask River flowed east, onto the melting ice sheet surface, to join the supraglacial Midcontinent River (on ice approximately 600 meters thick). Flaxville alluvial deposits were deposited second as the Midcontinent River sliced its ice-walled valley down into the ice sheet surface and the Alsask River eroded a bedrock-walled valley south and east of the alluvium-protected Cypress Hills channel. Third, as the Midcontinent River sliced down through the ice sheet surface, to form an ice-walled and bedrock-floored channel, significant Alsask River floodwaters, then flowing entirely east of the rising Rocky Mountain front and transporting debris-laden icebergs (from the ice sheet margin), were captured by the previously-described, southeast-flowing, Southwest River (3). Fourth, continued ice sheet melting opened up northern drainage routes (to Hudson Straits) and the Midcontinent River was dismembered. The Southwest River was next dismembered as northeast-oriented breaches opened up through the then detached Southwest Ice Sheet. The deep Missouri and Milk River valley complex, south of the alluvium-protected Flaxville channel, eroded headward when the Medicine Lake breach captured Southwest River flow. Next, the Tyner Valley breach captured all northern Alberta meltwater flow to north central Montana and dismembered the Alsask River. Fifth, climate deterioration caused periodic freezing of meltwater floods, temporarily closed gaps (e.g. Medicine Lake and Tyner valleys) through the Southwest Ice Sheet, and forced meltwater (when thawing occurred) to flow over the Tyner-Medicine Lake divide (cutting first the Big Muddy and Poplar River valleys and later the modern South Saskatchewan Valley) and over the Medicine Lake-Yellowstone divide (cutting the modern Missouri and related valleys east of Culbertson, Montana).

1. Storer, J. E. (1978) in Western and Arctic Canadian Biostratigraphy (Stelck, C. R. and Chatterton, B. D. E., eds) pp 595-602. Geological Association of Canada Special Paper 18.
2. Savage, D. E. and Russell, D. E. (1983) Mammalian Paleofaunas of the World, pp 114-400. Addison-Wesley Publishing, Reading, MA.
3. Clausen, E. N. (1996) Proc ND Acad Sci 50, 37

ORIGIN AND AGE OF EASTERN MONTANA AND WESTERN NORTH DAKOTA HIGH-LEVEL ALLUVIUM

Eric N. Clausen
Midcontinent Institute, Minot State University, Minot, ND 58707

Coarse-grained alluvium (usually mapped as middle and late Cenozoic in age) is located on eastern Montana's and western North Dakota's Redwater-Yellowstone, Yellowstone-Little Missouri, and Little Missouri-Missouri drainage divides. Previous workers have used paleontologic evidence to assign an Oligocene age to some of these western North Dakota sediments, various Tertiary and Quaternary ages to other deposits, and a Pleistocene age to segments of North Dakota's Missouri Valley-representing a time span claimed to be 28 to 33 million years in length (1). Yet, these eastern Montana and western North Dakota alluvial deposits and all adjacent valleys and other landforms can be explained by a continuous progression of events resulting from rapid meltdown of North America's only Cenozoic continental ice sheet and a single meltwater flow route, named here the Mondak River.

Source and destination of Mondak River water: The Mondak River was one of several flow routes which developed during Great Divide River dismemberment (2). Just prior to Mondak River development, the Great Divide River consisted of large meltwater floods, some of which flowed into the rising Rocky Mountains south and west of the northern Alberta ice sheet margin. Once within the Rocky Mountain region, this water flowed southeast through British Columbia (carving through valleys such as the Rocky Mountain Trench) and continued southeast across western Montana (also carving through valleys) to central Wyoming. The Mondak River flow route was established when regional uplift altered what had been southeast-oriented flow routes, across Wyoming, and diverted the meltwater floods northeast to the Saskatchewan and North and South Dakota ice sheet margin. The primary flow route was from northwest Wyoming, northeast across eastern Montana, to the southern Saskatchewan ice margin, where the Alsask River had cut a valley across the ice sheet surface which led to the southeast-flowing supraglacial Midcontinent River (3). Significant volumes of water also spilled out of the Mondak River channel and flowed directly east and southeast toward the North and South Dakota ice margin where the meltwater floods then flowed across the ice sheet surface and joined the previously-described Dakota River (2).

Mondak River History: Western North Dakota's oldest high-level alluvium was deposited when floods spilled from an early Mondak River (Cypress Hills level) and flowed east to the North and South Dakota ice sheet margin and crossed the ice sheet surface to join the then south-flowing supraglacial Dakota River. These early Mondak River floodwaters, which had crossed the rising Beartooth Mountains, transported distinctive coarse-grained clasts (4) and volcanic ash, carved valleys in western North Dakota's then high-level surface, and backfilled those valleys with coarse-grained alluvium and other sediments. Second, as the Alsask River cut its Flaxville Channel, the Mondak River carved a new channel, slightly south and east of its earlier channel, and water continued to spill eastward toward the Dakota River (still flowing south in an ice-walled, but then bedrock-floored valley). Western North Dakota's earlier high-level surface began to be stripped as ice sheet melting lowered baselevel and water moved southeast toward Southwest Ice Sheet low points. Third, a major breach around the Southwest Ice Sheet's south end established the Southwest River (2) and captured significant Mondak and Alsask river flow. Fourth, the Midcontinent River was dismembered (and the Dakota River reversed) when ice sheet melting opened up northern drainage routes. The Southwest River was next dismembered when breaches through the Southwest Ice Sheet opened up. The parallel Yellowstone and Little Missouri alignments became primary flow routes as water flowed south and east of earlier Mondak River alluvium toward the northwest North Dakota Southwest Ice Sheet margin and then east along that ice sheet margin toward an ice sheet breach at Lincoln Valley. The deep Little Missouri valley then formed as the Lincoln Valley headcut eroded upstream; the deep Cheyenne, Moreau, Grand, Cannonball, Heart, and Knife valleys formed when northeast-oriented headcuts eroded upstream from other Southwest Ice Sheet breaches and captured southeast-oriented flow (prior to being beheaded); and the deep Yellowstone Valley eroded headward when water broke through the Southwest Ice Sheet north of Williston. Fifth, climate deterioration caused freezing of meltwater floods, temporarily closed Southwest Ice Sheet breaches (like Lincoln Valley), and forced meltwater (when thawing occurred) to flow over divides between the northeast-oriented valleys and cut final segments of North Dakota's present-day Missouri Valley.

1. Kihm, A. J. and Lammers, G. E. (1986) Proc ND Acad Sci 40, 18
2. Clausen, E. N. (1996) Proc ND Acad Sci 50, 37
3. Clausen, E. N. (1997) Proc ND Acad Sci 51, 186
4. Clausen, E. N. (1982) Proc ND Acad Sci 36, 16

METHOD FOR PREPARATION OF TRABECULAR BONE MATRIX FOR HISTOLOGICAL STUDIES USING SCANNING ELECTRON MICROSCOPY

Laurie A. Crummy*[1], Joseph P. Idso[2], Samuel M. Newman Jr.[2], and Curtiss D. Hunt[2]
[1]Red River High School, Grand Forks, ND 58201
[2]USDA-ARS, Human Nutrition Research Center, Grand Forks, ND 58202-9034

Because trabecular (cancellous or spongy) bone has a higher turnover rate than does cortical (compact) bone, most metabolic bone diseases affect trabecular bone more than cortical bone (1). To improve the ability to assess the influence of various nutritional stressors on trabecular bone matrix morphology, we developed a chemical digestion technique to remove all adjacent cellular material from trabecular bone samples prior to examination by a scanning electron microscope (SEM). To ensure that the clearing technique did not alter bone matrix morphology, we verified the efficacy of the technique by utilizing bone from control rats and from rats exposed to moderate cholecalciferol (Vit.D), magnesium or boron deprivation, any of which induce alterations in trabecular bone morphology.

Proximal tibiae were isolated from 12 rats (3/group) fed 100 mg magnesium/kg diet (inadequate) and ~0.1 (low) or 2.0 (physiologic) mg boron/kg and 1000 IU Vit.D/kg throughout the experiment or between days 19 and 35 only. The proximal tibiae were halved in the frontal plane with a razor blade and placed in buffered formalin for 21 months. Subsequently, the halved proximal tibiae were cut again sagittally with a high speed circular saw to create duplicate experimental bone samples with similar structure. Both samples were immersed in 10 ml. ether, then 10 ml. 5% H_2O_2 (24 hours each). For the final digestion step (10 ml. 18% NaOH) one of the matching halves was treated for 16 hours, the other for 116 hours in random assignment. After chemical digestion, matching halves were dehydrated in a graded series (75, 85, 95%, 5 min each; 100% twice, 15 min each) of ethyl alcohol, critical point dried with CO_2, mounted side-by-side on the same stub, and sputter-coated with 30 nm palladium-gold according to standard procedures (2). Samples were examined at 16X, 62X, 320X, and 3600X in a scanning electron microscope.

Examination of the bone samples under lower power magnification (16X or 62X) revealed that a treatment period of 16 hours with NaOH was not sufficient to completely clear the trabecular bone of adjacent cellular material. In contrast, matched samples treated for 116 hours were clear of cellular material with trabeculae visible the depth of the sample. Use of a razor blade or circular saw did not induce discernable damage to the gross structure of exposed trabeculae. Because all bones were isolated from magnesium-deficient animals, it was not surprising to observe defects in the metaphysis in most bone samples. For example, the most visible abnormality of magnesium-deficient tibiae appeared as a paucity of trabeculae in the central region of the metaphysis. In its extreme, a large cavity devoid of trabeculae was formed in this area. Existing trabeculae did not exhibit any structural abnormalities and there was no indication of increased fragility.

Examination of matched bone samples under higher magnification (320X and 3600X) was carried out to ensure that chemical contact did not alter trabecular bone morphology by either removing bone matrix in a uniform manner or by differentially eroding specific trabecular features. Gross trabecular structure was not different between any of the matched samples, even under conditions of extreme dietary stress. Also, the width of individual trabeculae did not vary discernably between matched samples. At 320X, osteoblast lacunae and possible cannilicular channels were visible regardless of chemical treatment and the morphology of either was similar in matched samples. At 3600X, sheets of highly oriented fibers, assumed to be collagen fibers, comprised the osteoid surface of the trabeculae. Filamentous material, each filament the size of a collagen fiber, sometimes extended singly, or in groups, between and attached to the bases of adjacent trabeculae. The duration of chemical contact apparently did not alter the width of the filaments. While there was a differential removal of delicate soft tissues with the two treatment times (16 hours versus 116 hours) with soft tissue remnants retained at 16 hours, the appearance of the dense osteoid material was not affected by the longer 116 hour treatment.

For purposes in which removal of the osteoid is undesirable, the method we describe is preferable to other chemical digestion processes, for example, sodium hypochlorite digestion, where exposure to low concentrations (4.5%) of the chemical for short periods of time (60 min.) completely removes the osteoid (3). The described method is satisfactory for removing soft tissue from bone without risk of damaging the bone itself.

1. Alhava, E.M. (1991) Calcif Tissue Int 49, S21-S23.
2. Newman, S.M., McDonald, I.C., Triebold, B. (1993) Int J Insect Morphol & Embryol, Vol.22 No.5, pp 535-547.
3. Jayasinghe, J.A.P., Jones, S.J., Boyde, A. (1993) Virchows Archiv A Pathol Anat 422:25-34.

DIADENOSINE PENTAPHOSPHATE ACTIVATES PURINOCEPTORS AND RELEASES INTRACELLULAR CALCIUM FROM CAFFEINE/RYANODINE-SENSITIVE STORES IN HUMAN FETAL ASTROCYTES

Dolhun Brian A[1*], Holden Clark P[1], Nath Avindra[2], and Geiger Jonathan D[1]
Departments of Pharmacology and Therapeutics[1], and Medical Microbiology and Neurology[2], University of Manitoba Faculty of Medicine, Winnipeg, Manitoba, R3E OW3 Canada.

A group of adenosine-based compounds termed diadenosine polyphosphates (Ap_nAs, n= 2 to 6 phosphate groups) act as agonists on P_2-type adenine nucleotide purinoceptors, increase levels of intracellular calcium ($[Ca^{2+}]_i$), and act as modulators of brain and muscle ryanodine receptor intracellular calcium release channel complexes (RyRs). In this study, using single cell fluorescence techniques and cultured human fetal astrocytes loaded with the calcium sensitive dye fura-2/AM to measure free $[Ca^{2+}]_i$, we determined the extent to which and the mechanisms by which P^1, P^5-di(adenosine-5') pentaphosphate (Ap_5A) increased $[Ca^{2+}]_i$. Ap_5A, pressure ejected from micropipettes filled with 100 µM Ap_5A, produced statistically significant increases in $[Ca^{2+}]_i$ from basal levels of 141 ± 12 nM to 980 ± 150 nM in 55 out of 95 cultured human fetal astrocytes tested. These actions of Ap_5A were mediated, at least in part, through activation of purinoceptors because the nonselective P_{2X}/P_{2Y} purinoceptor antagonist pyridoxal-phosphate-6-azophenel-2',4'-disuphonic acid tetrasodium (PPADS), at a final concentration of 300 µM, blocked, by 52%, Ap_5A-induced increases in $[Ca^{2+}]_i$. Initial studies showed that chelation of extracellular Ca^{2+} with 2 mM EGTA prevented Ap_5A-induced increases in $[Ca^{2+}]_i$. Subsequently, thapsigargin (5 µM), a Ca^{2+}- ATPase inhibitor that depletes intracellular stores of $[Ca^{2+}]_i$, was found to block, by 58%, Ap_5A-induced increases in $[Ca^{2+}]_i$. Thus, Ap_5A - induced increases in $[Ca^{2+}]_i$ originated extracellularly and intracellularly. The calcium released from intracellular stores was from RyR- and not inositol 1,4,5- trisphosphate (IP_3) - regulated stores because caffeine and ryanodine blocked by approximately 66%, but bradykinin did not block Ap_5A-induced increases in $[Ca^{2+}]_i$. The presence of RyR - regulated stores of calcium was confirmed by results that pressure applied ryanodine (100 nM) increased $[Ca^{2+}]_i$ by 723 ± 298 nM. Pressure application of 100 nM ryanodine following pretreatment with 5 µM thapsigargin resulted in increases in $[Ca^{2+}]_i$ of only 33 ± 4 nM ($P<0.0001$). In cultured human fetal astrocytes, Ap_5A activates P_{2X}/P_{2Y} purinoceptors and significantly increases levels of Ca^{2+} by increasing the influx of Ca^{2+} which stimulates the release of $[Ca^{2+}]_i$ from ryanodine/caffeine sensitive intracellular stores.

THYROID HORMONES REGULATE THE RESYNTHESIS OF PHOSPHATIDYLETHANOLAMINE IN RAT HEART

Vernon Dolinsky* and Grant M. Hatch
Departments of Biochemistry and Molecular Biology and Pharmacology and Therapeutics,
Faculty of Medicine, University of Manitoba, Winnipeg, Manitoba, Canada, R3E 0W3

Membrane bound phospholipids require a distinct fatty acid composition. This is achieved through the deacylation-reacylation cycle that involves the breakdown of the parent phospholipid to a fatty acid and its lysophospholipid derivative by a phospholipase A activity. Phospholipids are resynthesized through the action of an acyltransferase that attaches acyl-CoA thioesters to the lysophospholipid. This cycle must be carefully regulated so that the correct fatty acid composition of the phospholipids is maintained otherwise the normal functioning of the membrane may be jeopardized. Thyroid hormones have profound effects on the heart (1). Since it is established that thyroid hormones regulate a number of lipid metabolizing enzymes (2), it is possible that the deacylation-reacylation cycle of certain phospholipids may also be regulated by thyroid hormones.

To test this hypothesis, rats were treated with thyroxine (250 μg/kg body weight) for 5 consecutive days to induce a hyperthyroid condition, then their hearts removed and perfused for 30 min in Langendorff mode (3) with Krebs-Henseleit buffer (4) containing [1-^{14}C]oleate (18:1) bound to albumin in a 1:1 molar ratio. Saline treated animals served as controls. A 2.4-fold increase in the formation of [^{14}C]phosphatidylethanolamine (PE) was observed in the hearts of thyroxine treated animals compared with controls, when the data was expressed as dpm/g ventricular weight. No statistically significant differences in the formation of other [^{14}C]phospholipids were observed in the hearts of thyroxine treated animals compared with controls. When rat hearts were perfused with other radiolabeled fatty acids, a similar pattern was observed. A 2-fold increase in the formation of [^{14}C]PE was observed in thyroxine treated hearts perfused with [1-^{14}C]palmitate (16:0) and [1-^{14}C]linoleate (18:2) bound to albumin, compared with controls.

The effect of thyroxine treatment of rats on the pool size and the *de novo* biosynthesis of PE in the heart was investigated. The pool size of PE was determined using the sensitive lipid phosphorous assay (5). When expressed as nmoles/g ventricular heart weight, no changes in the pool size of PE in the rat heart of control and thyroxine treated animals was observed. The *de novo* biosynthesis of PE was measured in hearts perfused for 30 min with [1,2-^{14}C]ethanolamine. No significant changes in the labeling of [^{14}C]PE nor other aqueous ethanolamine containing metabolites were observed in the thyroxine treated hearts as compared to controls when the data was expressed as dpm/g ventricular weight.

These results suggested that thyroxine affects the resynthesis of PE. Acyl-CoA:1-acylglycerophosphoethanolamine acyltransferase activity was measured as described previously (6) in rat heart microsomes. The acylation of PE from [^{14}C]oleoyl-Coenzyme A was increased in thyroxine treated hearts compared to controls. Interestingly, rats administered 0.05% 6-n-propyl-2-thiouracil in their drinking water for 5 consecutive days to induce a hypothyroid condition (7), also showed a 33% lowered acylation of PE from [1-^{14}C]oleoyl-Coenzyme A in rat heart microsomes compared with controls.

The results presented here indicate that acyl-CoA:1-acylglycerophosphoethanolamine acyltransferase activity is markedly affected by the thyroid state of the animal. We believe that these observations suggest that thyroid hormones regulate the PE deacylation-reacylation cycle. This should provide the first evidence that proves thyroid hormones can regulate the lipid composition of membranes through the deacylation-reacylation cycle of a major phospholipid. Studies that will determine the effect of thyroid hormones on cardiac phospholipase A activity directed towards PE are forthcoming. In addition, the effect of thyroid hormones on the fatty acyl species of PE will be determined. These results, will provide a complete picture of how thyroid hormones regulate the deacylation-reacylation cycle of PE.

1. Aronow, W.S. (1995) Clin Ger Med 11, 219-229.
2. Hoch, F.L. (1988) Prog Lipid Res 27, 199-270.
3. Langendorff, O. (1895) Pfluegers Arch 61, 291-332.
4. Krebs, H.A. and Henseleit, K. (1932) Hoppe-Seyler's Z Physiol Chem 210, 33-66.
5. Rouser, G., Siakotos, A.N. and Fleischer, S. (1966) Lipids 1, 85-86.
6. Arthur, G., Page, L. and Choy, P.C. (1987) Biochim Biophys Acta 921, 259-265.
7. Paradies, G. and Ruggiero, F.M. (1989) Arch Biochem Biophys 269, 595-602.

IDENTIFICATION OF A NOVEL ALLELE AT THE HUMAN *NAT1* ACETYLTRANSFERASE LOCUS

Mark A. Doll*, Wen Jiang, Anne C. Deitz, Timothy D. Rustan, and David W. Hein
Department of Pharmacology and Toxicology,
University of North Dakota School of Medicine and Health Sciences
Grand Forks, ND 58202-9037

Humans possess two *N*-acetyltransferase isozymes (NAT1 and NAT2). Until recently only *NAT2* was known to be polymorphically expressed segregating individuals into rapid, intermediate, and slow acetylator phenotypes. However, an acetylation polymorphism recently has been reported for *NAT1*. Seven *NAT1* alleles identified in human populations (*NAT1*3, *4, *5, *10, *11, *14*, and **15*) have been formally named whereas one other (V_A) will be designated *NAT1*16*. In this study we have cloned and sequenced a novel *NAT1* allele (Genbank HSU 80835) that contained nucleotide substitutions at -344 (C→T), -40 (A→T), 445 [G→A(Val→Ile)], 459 [G→A(silent)], 640 [T→G(Ser→Ala)], a 9 base pair deletion between nucleotides 1065 and 1090, and 1095 (C→A). Thus, the novel *NAT1* allele which we have designated *NAT1*17* is similar to *NAT1*11* except for a G^{445}A substitution (Val→Ile) in the *NAT1* coding region. The effect of the G^{445}A (Val^{149} Ile) substitution in the *NAT1* coding region was determined by recombinant expression of NAT1 proteins in *Escherichia coli* strain JM105. The G^{445}A (Val^{149}→Ile) substitution yielded no significant changes in levels of immunoreactivity, as detected by Western blot with anti-human NAT1 antiserum, nor in intrinsic stability of the recombinant N-acetyltransferase protein. However, the G^{445}A (Val^{149}→Ile) substitution yielded expression of recombinant human NAT1 protein that catalyzed the *N*-acetylation of aromatic amines and the *O*- and *N,O*-acetylation of their *N*-hydroxylated metabolites at rates up to 2-fold higher than wild-type recombinant human NAT1.

N-Acetyltransferase Activities of Recombinant Human *NAT1*^{wt} and *NAT1*^{445}

Substrate	Enzyme	Activity (nmole/min/U)
p-Aminobenzoic Acid	NAT1^{wt}	4111 ± 113
	NAT1^{445}	6304 ± 116
p-Aminosalicyclic Acid	NAT1^{wt}	2923 ± 79
	NAT1^{445}	4228 ± 78
Isoniazid	NAT1^{wt}	12.2 ± 0.4
	NAT1^{445}	16.3 ± 0.2

Table values represent the mean ± SEM for 3-4 individual determinations. *N*-Acetyltransferase activities catalyzed by recombinant NAT1^{445} were significantly ($p<0.001$) higher than recombinant NAT1^{wt} for each substrate following Student's t-test.

This work was partially supported by USPHS grant CA-34627 from the National Cancer Institute.

THE INVENTORYING OF SAND AND GRAVEL DEPOSITS IN THE BISMARCK-MANDAN AREA, ND

Jonathan B. Ellingson*
Department of Geology and Geological Engineering, University of North Dakota, Grand Forks, ND 58202

The sand and gravel industry is the largest nonfuel mineral industry in the nation. In 1995, the production of sand and gravel totaled 910 million metric tons valued at $4.2 billion. Currently there are 4,300 companies producing sand and gravel in the United States. Construction sand and gravel accounts for 96% of the total production, of which 42% was used for concrete aggregate, 24% for road base and coverings, 14% as asphaltic concrete aggregates, 13% for construction fill, 2% for concrete products, 1% for plaster and gunite sands, and 4% for miscellaneous uses. Industrial sand accounts for the remaining 4%, of which 39% was used for glassmaking, 22% in foundries, 6% for abrasives, 5% for hydraulic fracturing, and 28% for miscellaneous uses (1).

Sand and gravel are high-bulk, low-value commodities; therefore, transportation costs account for a considerable amount of the delivered price. Land-use conflicts involving sand and gravel mining and urban development are becoming increasingly more common. Cities expand into adjacent rural areas, thus covering deposits; residential development occurs adjacent to sand and gravel sources causing opposition of nearby homeowners; and depletion of sand and gravel resources occurs due to high use in metropolitan areas. It is strongly recommended that aggregate lands within metropolitan areas be inventoried to define the quantity and quality of available sand and gravel deposits before they are irretrievably lost to urban sprawl. The inventory of sand and gravel resources is intended to assist planners in making land-use and zoning decisions.

The price paid for sand and gravel by the consumer varies considerably, depending upon local supply, demand, and transportation costs. The market for sand and gravel shifts quickly and is guided by the needs of the consumer. The supply and demand for sand and gravel can shift significantly with a large or small construction project, such as minor road repair, installation of new roads, highway construction, growth of urban areas, etc. For this reason, it is necessary that sand and gravel resources be inventoried to aid in the planning of future construction projects.

Inventorying of these sand and gravel deposits consists of mapping the Bismarck-Mandan area and determining the quantity and quality of the deposits. The Bismarck-Mandan urban area is one of the fastest growing metropolitan areas in North Dakota; it was selected for this project by recommendations from the North Dakota Geological Survey (NDGS), the State Mapping Advisory Committee, and the Missouri River Basin Earth Resources Mapping Group, as the number one priority for mapping in the State. The NDGS has been funded to map seven of the nine quadrangles that constitute this area; the remaining two quadrangles must be mapped to complete this investigation. The Lynwood Quadrangle was mapped last summer and the Harmon Quadrangle will be mapped this summer.

Proper geological exploration and evaluation, including mapping, drilling, trenching, and laboratory testing, is of critical importance in finding, assessing, and developing new deposits. Geological mapping of this area is accomplished by examining glacial sediments and landforms using remote sensing, topographic maps, subsurface data, and on-site evaluation. Remote sensing techniques (including aerial photographs) and topographic maps are analyzed to help identify and determine the extent of glacial landforms. Several sand and gravel bearing landforms, including eskers and outwash plains were located this way. Subsurface data consists of well logs from domestic water wells, information obtained from extensive drilling, as well as trenching. Approximately 130 holes were drilled using a Giddings soil probe, ranging in depth from 1 to 10 m. A Geographic Information System (GIS) is being used to compile the data and construct a final map.

Samples are collected throughout the drilling and trenching process, as well as from outcrops and surface exposures. These samples are used to determine the quality of the sand and gravel and ultimately their fundamental potential. The quality of sand and gravel depends upon the physical and chemical properties of the aggregates. These properties are determined through a series of tests which measure the soundness and durability of the aggregate. Soundness and durability are the terms used to denote the ability of an aggregate to retain a uniform physical and chemical state over a long time. Specifications define the tests and critical observations that are made on sand and gravel and the limiting values that must be achieved before an aggregate is considered suitable for a particular use. Specifications controlling the qualities of sand and gravel are variable, depending upon the purpose for which the aggregate is to be used. Petrographic examination is being used to determine such properties. Standard tests and specifications used by the American Society for Testing and Materials, the Department of Transportation, and other testing agencies are being completed to determine the soundness, durability, and uses of the aggregate.

The results of this study will provide local planners with the necessary information to make better land-use decisions regarding sand and gravel resources and to conserve these deposits for future use.

1. USGS, (1996), Sand and Gravel (Construction), Internet information, http://minerals.er.usgs.gov/minerals/pubs/mcs/.

EXPLOSIVE AND BLASTING TECHNIQUES USED TO ACHIEVE OPTIMUM FRAGMENTATION IN TACONITE MINES OF NORTHERN MINNESOTA

Jonathan B. Ellingson*
Department of Geology and Geological Engineering, University of North Dakota, Grand Forks, ND 58202

Explosive and blasting techniques were examined at three taconite mines in Northern Minnesota to determine if a standard set of parameters could be determined to achieve optimum fragmentation. Optimum fragmentation is reached when the total 1) crushing and milling, 2) loading and hauling, and 3) drilling and blasting costs are minimized (Figure 1). The costs of loading, hauling, crushing, and milling are all decreased as the rock becomes more fragmented during the blasting process, however if the rock is fragmented too much, the cost of drilling and blasting continues to increase with little or no benefit to the other processes.

Blasting is a very important aspect of mining; it can make up approximately 60% of the total cost of production, therefore, optimum fragmentation must be established. Three important blast design principles must always be kept in mind: 1) explosive energy seeks the path of least resistance, 2) there must be a free face parallel to the explosive column at the time of detonation, and 3) there must be adequate void space into which the broken rock can expand. Desirable effects of blasting include rock fragmentation and muckpile displacement, whereas undesirable effects include flyrock, ground vibration, and airblast (concussion). The correct combination of blasting parameters can, therefore, maximize the desirable and minimize the undesirable effects.

The parameters that were examined in this study included hole diameter, bench height, spacing, burden, hole pattern, sub-drilling, stemming, stemming type, powder factors, base charges and densities, top charges and densities, tons per blast, and drilling costs (Table 1). These parameters were collected through personal discussion with the blasting engineers and staff at the three mines: Hibbing, Minntac, and National Steel. High speed photography was utilized to help detect blast deficiencies. Fragmentation is difficult to measure, thus it was analyzed by the wear and tear on the machinery used for loading and hauling, and especially by the crusher efficiency. Several parameters and techniques were adjusted through the introduction of new mathematical equations and models.

The results of this study indicate that no single set of blasting parameters can be pre-determined and used for every blast. Natural variations (undulating surfaces, void spaces, fractures, etc.) occurring within the rock formation, as well as compensating for design changes and previously blasted areas, make it impossible to use a standard set of parameters for every blast. Each blast must be dealt with individually; corrections and design changes must be made sometimes one row or even one hole at a time. Nonetheless, the blasting pattern proved to be the most important parameter involved; the staggered blasting pattern proved to be much more efficient than the square (Figure 2). Minntac converted from the square pattern to the staggered pattern and saved approximately $300,000 in blasting costs alone the first year; this increased the energy units/ft of rock by 29.9%.

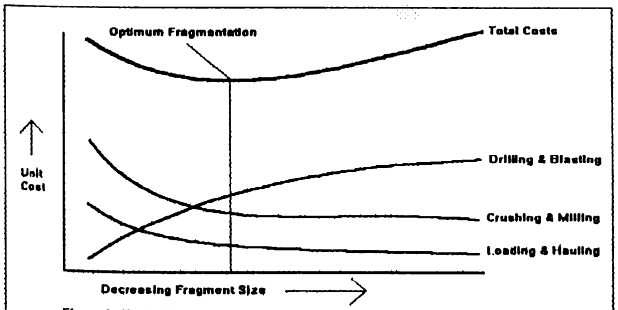


Figure 1. Typical Costs of Mining Operations and Optimum Blasting Definition

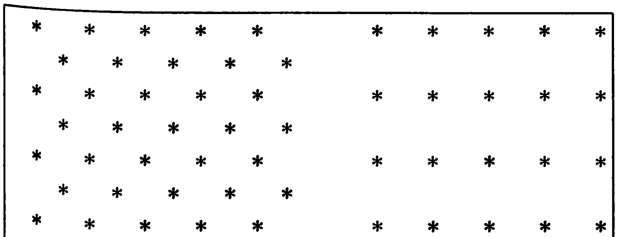


Figure 2. Staggered Pattern vs. Square Pattern

Property	Hibbing	Minntac	Nat. Steel
Hole Diameter	16 inches	16 inches	15 inches
Bench Height	45 feet	40 feet	45 feet
Spacing	44 feet	32 feet	32 feet
Burden	38 feet	32 feet	28 feet
Hole Pattern	Staggered	Square	Staggered
Sub-Drilling	5 feet	3 feet	3 feet
Stemming	15 feet	16 feet	15 feet
Stemming Type	Cuttings	Crushed Rock	Screened
Powder Factor	0.4 lbs/yd³	0.6 lbs/yd³	0.9 lbs/yd³
Base Charge	Emulsion	Water Gel	Emulsion
* Density	1.36	1.30	1.36
Top Charges	ANFO	ANFO	ANFO
* Density	0.85	0.85	0.85
Tons/Blast	690,000	750,000	930,000
Drilling Costs	$6.00/ft	$6.00/ft	$6.00/ft

Table 1. Blasting Parameters used at Mines

URINARY BLADDER AND COLON TUMORS IN RAPID AND SLOW ACETYLATOR CONGENIC HAMSTERS ADMINISTERED 3,2′-DIMETHYL-4-AMINOBIPHENYL

Yi Feng[1,2]*, Timothy D. Rustan[1], Adrian J. Fretland[1], Amy M. Becker[2], A. Marvin Cooley[3], Kap J. Lee[4], William K. Becker[2], and David W. Hein[1]
[1]Departments of Pharmacology and Toxicology, [2]Surgery, [3]Pathology, and [4]Biomedical Research Center
University of North Dakota School of Medicine and Health Sciences,
Grand Forks, ND 58202-9037

Aromatic amines are a group of common environmental carcinogens. They are procarcinogens and need to be biotransformed to ultimate carcinogens by a series of enzymes *in vivo*. Ultimate carcinogens cause genetic lesions and initiate tumorigenesis. *N*-acetyltransferase (NAT2) is an important enzyme involved in the metabolism of aromatic amines. A genetic *NAT2* polymorphism segregates humans and other mammals such as hamsters into rapid and slow acetylator phenotypes. Results from human epidemiological studies have shown inconsistent relationships between incidences of various cancers and acetylator phenotypes. Human epidemiological studies are subject to many uncontrolled factors. Therefore, it is important to test those hypotheses in appropriate animal models. In the present study, 3,2′-dimethyl-4-aminobiphenyl (DMABP), a model urinary bladder and colon aromatic amine carcinogen, was administered to rapid and slow acetylator Syrian hamsters congenic at the *NAT2* locus.

Fifty male and 50 female age-matched rapid and slow acetylator congenic hamsters were administered weekly s.c. injections of DMABP (100 mg/kg) for 26 weeks, followed by biweekly s.c. injections of DMABP (100 mg/kg) for 12 weeks, and were maintained for up to another 6 months. All female but only 16% of male hamsters died during the period of DMABP administration. Five rapid and five slow acetylator congenic hamsters were administered vehicle (DMSO/H_2O: 1/1 v/v) as controls. Hamsters were anesthetized with 2,2,2-tribromoethanol (300 mg/kg) and 10 ml of 0.2% methylene blue in 0.1 M sodium phosphate buffer (pH 7.4) was injected slowly into the large intestine from the anus. The rectum, colon, and cecum were removed, opened longitudinally, washed in 0.9% NaCl, pinned out flat, and fixed for 1 hr in 4% paraformaldehyde in 0.1 M sodium phosphate buffer (pH 7.4). The urinary bladders were also removed, stained, pinned out flat and fixed. Aberrant crypt foci (ACF) and tumors in the large intestine and urinary bladders were scored blind with a dissecting microscope. Tumors were further confirmed by histological examination. Codons 12 and 13 of the Ki-ras oncogene were examined in normal mucosa, ACF polyps and urinary bladder tumors by PCR direct sequencing.

No ACF in large intestine and no urinary bladder tumors were observed in control animals. A limited number of polyps were found in the large intestine of two rapid and two slow acetylator control animals. ACF and polyps were observed in the large intestine of all rapid and slow acetylator hamsters administered DMABP. ACF were more frequent in the cecum and ascending colon and polyps were more frequent in the transverse colon. Frequencies of ACF and polyps did not differ significantly between rapid and slow acetylators. Urinary bladder carcinomas ranged from grade I to III in both rapid and slow acetylator male hamsters, but differences between the phenotypes were not significant. No metastatic tumors from the colon and urinary bladder were found in other tissues such as lung, liver, spleen, stomach, small intestine, or prostate. No mutations in codons 12 and 13 of the Ki-ras oncogene were detected in normal mucosa, ACF, polyps or urinary bladder tumors.

This work was partially supported by USPHS grant CA-34627 from the National Cancer Institute.

THE RATE OF AMANTADINE UPTAKE IS INCREASED IN RENAL CORTICAL TUBULES ISOLATED FROM DIABETIC OR UNINEPHRECTOMIZED RATS

Kerry B. Goralski* and Daniel S. Sitar,
Clinical Pharmacology Section and Deptartment of Pharmacology and Therapeutics, University of Manitoba, Winnipeg, Manitoba R3E 0W3.

It is well known that unilateral nephrectomy and early stage insulin dependent diabetes mellitus (IDDM) are two conditions causing renal hypertrophy and hyperfiltration. Much less is known about how renal hypertrophy effects the renal tubule secretion and reabsorption of exogenous xenobiotics. We hypothesize that changes in renal function associated with uninephrectomy and IDDM may alter renal tubule transport and thus renal elimination of organic cationic drugs. The effects of early stage diabetes and unilateral nephrectomy on the renal tubule transport of [^{3}H]-amantadine (an organic cation) was investigated. Kidneys were obtained from streptozotocin-induced diabetic rats (+/- insulin treatment), uninephrectomized (UNX) and control, male Sprague-Dawley rats. Methods for diabetic rat preparation and confirmation of the diabetic state, and preparation of UNX rats were according to published procedures (1, 2). Renal cortical proximal and distal tubules were isolated by collagenase digestion followed by Percoll density gradient centrifugation. The isolated tubules were incubated for 30 sec in Krebs-Henseleit solution (KHS) with varying concentrations of [^{3}H]-amantadine. The reaction was terminated by rapid filtration through glass filters. The filters were then assayed for radioactivity by scintillation counting and renal tubule amantadine accumulation was determined. Kinetic parameters Km and Vmax were calculated using the Michaelis-Menten equation.

TABLE 1. Km and Vmax (mean ± SE, minimum n=3) for amantadine uptake in renal cortical proximal and distal tubules from normal rats and diabetic (± insulin treated) rats. * $p < 0.05$, ANOVA, compared to control.

	Km (μM)			Vmax (ηmol/mg protein/min)		
	Control	Diabetic	Diab +Insulin	Control	Diabetic	Diab +Insulin
Tubule						
Proximal	66.5 ± 13.5	81.1 ± 6.4	73.4 ± 10.1	4.07 ± 0.68	7.84 ± 0.85*	4.99 ± 0.78
Distal	61.5 ± 10.6	84.9 ± 2.8	89.9 ± 10.5	4.58 ± 0.57	5.23 ± 0.38	5.44 ± 0.15

TABLE 2. Km and Vmax (mean ± SE, minimum n=3) for amantadine uptake in renal cortical proximal and distal tubules from normal rats and uninephrectomized rats. * $p < 0.05$, unpaired t-test, compared to control.

	Km (μM)		Vmax (ηmol/mg protein/min)	
	Control	UNX	Control	UNX
Tubule				
Proximal	63.5 ± 9.99	90.4 ± 18.6	4.25 ± 0.51	7.57 ± 0.92*
Distal	57.7 ± 8.98	82.4 ± 7.53	4.13 ± 0.63	6.26 ± 1.65

The Vmax for amantadine uptake in the proximal tubules of diabetic rats and UNX rats was higher than the respective controls, $p < 0.05$ (Tables 1 and 2). The Vmax for amantadine uptake in the proximal tubules of insulin-treated diabetic rats approached control values and may be lower ($p < 0.07$) than the non-treated diabetic rats (Table 1). The Vmax values for distal tubules were not altered in the diabetic (± insulin), or the UNX rats (Tables 1 and 2). The potential effect of treatment on Km for amantadine uptake in proximal and distal tubules requires further evaluation.

In conclusion, it appears that unilateral nephrectomy and the renal pathological effects of early stage diabetes result in a similar selective increase in renal organic cation transport capacity in the proximal tubule. The increase in proximal tubule transport capacity associated with the streptozotocin-induced diabetic state may be reversed by insulin treatment. The implications of these data with respect to renal elimination of organic cations *in vivo* remains to be evaluated.

1. Hatch, G.M., Cao, S.G., and Angel, A. (1995) Biochem. J. 306, 1-6.
2. Intengan, H.D., and Smyth, D.D. (1996) British Journal of Pharmacology, 119, 663-670.

BOREHOLE TEMPERATURE PROFILES SHOW WARMING OF NORTH AMERICA

William D. Gosnold* and William L. Schmidt
Department of Geology and Geological Engineering, University of North Dakota, Grand Forks, ND 58202

Ground surface temperature varies regularly on diurnal, seasonal and annual scales and irregularly in response to synoptic weather patterns, interannual climate variability and long-term climate change. The thermal signals diffuse in space and with time so that each variation becomes negligible over a vertical depth related to the period of variation and to the thermal diffusivity of the ground. The thermal diffusivity of most rocks and soils is such that diurnal signals effectively disappear below 0.5 to 1.0 meters, annual signals disappear below about 20 to 30 meters, but century-scale signals are detectable over lengths of hundreds of meters. This means that short-period signals, e.g., interannual variability, are filtered by the diffusion process, thus eliminating the statistical uncertainty that is commonly associated with interannual variability in the air temperature data. An important property of this data set is that it is a direct temperature-temperature measurement and does not involve proxy data. Thus, the vertical temperature profile in a borehole contains a record of ground surface temperatures over the past several centuries and the record can be directly related to the climate at the borehole.

We have applied this method along a north-south transect in the mid-continent of North America where simulations of global warming based on a doubling of atmospheric CO_2 suggest that the amplitude of warming in North America should increase poleward (1,2,3). A critical consideration in this study was acquisition of borehole profiles that do not contain temperature signals unrelated to climate change (4). Fortunately, both the topography and geology of the Northern Plains transect provide favorable conditions for acquisition of reliable borehole data for climate reconstruction. The flat topography of the mid-continent region reduces the potential for adverse effects due to ground water flow, microclimates, and topographic distortion of the near-surface geothermal gradient. Therefore, if the warming trend predicted by GCM's is occurring, this mid-continent transect offers a favorable study area for detecting the signal with borehole temperature measurements.

Approximately 116 high-quality boreholes that were drilled as heat flow sites lie within the transect between southern Manitoba and northern Texas. We evaluated T-z profiles, terrain, bedrock lithology, and microclimatic factors for these sites and rejected all but 29 for climate reconstruction. Temperature profiles excluded were obtained from boreholes that either penetrated permeable bedrock, exhibited significant vertical variability in thermal conductivity, were drilled in hilly terrain, or may have experienced microclimatic disturbances related to land use/land cover changes. Twenty-one of the selected boreholes were drilled entirely in the Pierre Shale and one, a new heat flow site at Gunter, Texas, was drilled entirely in the Eagle Ford Shale (Cretaceous). The remaining holes were drilled in lower Tertiary age shales and shaley siltstones that have thermal properties similar to those of the Pierre Shale (5).

The ground-surface temperature (GST) histories, determined from this carefully selected set of 29 borehole temperature profiles, show a warming trend over the last century that increases systematically with latitude, i.e., from +0.4 °C at 41.1°N to +2.0 °C at 49.6°N. Surface air temperature (SAT) warming in the transect, determined from Historical Climatology Network stations, increases from +0.5 °C per century at 40°N to +1.6 °C per century at 48.8°N. These warming trends agree with the regional warming pattern predicted by GCM simulations of global warming. However, the magnitudes of warming determined from the GST and the SAT data agree in regions where seasonal ground freezing does not occur but differ significantly where seasonal ground freezing does occur. Analysis of ground and air temperature coupling suggests that the greater warming observed in the GST histories in seasonally frozen ground is due to a secular increase in soil moisture that corresponds with increased precipitation during the past 50 years. Thus, the borehole temperature profile does not simply retain a record of air temperature; it retains a combined signal that integrates temperature with the thermal effects of latent heat released during freezing and thawing of soil moisture and the insulating effect of snow cover.

1. Bretherton, F. P., Bryan, K., and Woods, J.D., (1990) In Climate Change - The IPCC Scientific Assessment, Houghton, J.T., Jenkins, G.J., and Ephraums. J.J. (eds). pp. 173-194, Cambridge University Press.
2. Hansen, J. E., Fung, I, Lacis, A., Rind, D., Lebedeff, S., Ruedy, R, Russell, P., and Stone, P., (1988) J. Geophys. Res., 93, 9341-9364.
3. Mitchell, J.F. B., S Manabe, V. Meleshko, T. Tokioka. (1990). In Climate Change - The IPCC Scientific Assessment, J.T. Houghton, G.J. Jenkins, and J.J. Ephraums (eds.) pp. 131-172, Cambridge University Press.
4. Lewis, T. J., and Wang, K., (1992) Palaeogeog., Palaeoclim., Palaeoecol., (Global and Planetary Change Section) 98:.87-100.
5. Gosnold, W. D., Jr., (1990) J. Geophys. Res. v. 95, p. 353-374.

STIMULATION OF THE PARAVENTRICULAR NUCLEUS OF THE HYPOTHALAMUS ALTERS RENAL FUNCTION IN THE ANESTHETIZED RAT

James R. Haselton*, Karilyn K. Avery, Hua Tu, Brian M. Walter and Richard C. Vari
Dept. of Physiology, Univ. North Dakota, School of Medicine & Health Sciences, Grand Forks, ND 58202

Purpose. The paraventricular nucleus of the hypothalamus (PVN) influences body fluid homeostasis. One group of neurons, the magnocellular neurosecretory cells which give rise to nerve terminals in the posterior pituitary, influences renal function via the release of arginine vasopressin (AVP) into the circulation. Another group of neurons, the parvocellular "autonomic-related" cells, may influence renal function via a direct neural link to the kidney (1). Several lines of evidence, based on anatomical (1), electrophysiological (2, 3) and physiological (4) studies, have supported the existence of a monosynaptic projection from these "autonomic-related" cells in PVN to the kidney in the rat. None of these studies has, however, sought to determine if these "autonomic-related" cells are capable of influencing renal function. We sought, with this study, to provide evidence that this neural pathway is capable of influencing renal function in rats.

Method. PVN neurons were activated (*i.e.*, disinhibited) with stereotaxically placed bilateral microinjections of bicuculline (BIC; 90 fmol; 100nl inj, 90μM solution). Renal function was assessed with standard techniques (clearance of inulin and *para*-aminohippurate). The variables that were measured, or calculated, were: glomerular filtration rate (GFR), PAH clearance (Cpah), urine flow (UV), urinary sodium excretion (UNaV), systemic mean arterial pressure (MAP), and heart rate (HR). Five groups of rats (anesthetized with Brevital and Inactin) were examined: time control (n=4), experimental (BIC injected in PVN; n=9), anatomical control (BIC injected outside PVN; n=8), vehicle control (NaCl injected in PVN; n=5), and a humoral control (treated with vasopressin V1 receptor antagonist and BIC injected in PVN; n=5). All injection sites were histologically verified. Data were tested statistically with repeated measures and factorial ANOVA (Fisher's PLSD post-hoc).

Results. All variables remained stable in the time control group. The values measured for all variables, measured before (baseline) and after BIC injection in PVN, for both the experimental group and humoral control group are shown in the following table (* p<.05, compared to respective baseline condition).

Variable	Experimental group Baseline	Experimental group BIC in PVN	Humoral control group V1A Baseline	Humoral control group V1A BIC in PVN
GFR (ml/min/g)	1.1 ± 0.1	0.5 ± 0.1*	1.5 ± 0.1	0.2 ± 0.1*
Cpah (ml/min/g)	2.8 ± 0.2	0.8 ± 0.3*	3.6 ± 0.2	0.8 ± 0.2*
UV (μl/min)	7.3 ± 0.2	3.3 ± 1.1	99.4 ± 35.6	27.6 ± 9.2*
UNaV (μEq/min)	0.3 ± 0.04	0.1 ± 0.02	3.1 ± 0.1	0.8 ± 0.3*
MAP (mm Hg)	118 ± 2	137 ± 5*	126 ± 1	152 ± 3*
HR (beats/min)	376 ± 2	441 ± 13*	380 ± 2	471 ± 14*

These results were not reproduced when BIC was injected outside PVN, or its vehicle (saline) was injected in PVN. Treatment of rats with a vasopressin type 1 receptor antagonist, to preferentially block the vasopressor effects of circulating vasopressin, did not alter any of the components of the response evoked following bilateral microinjections of BIC in PVN (see table above).

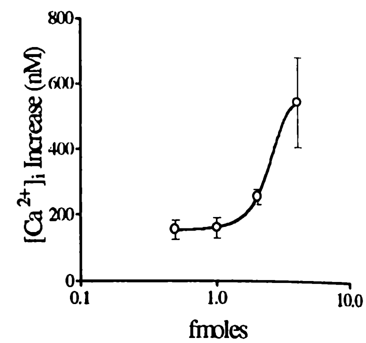
Conclusions. Activation of neurons in PVN evokes renal vasoconstriction and, thereby, a reduction in sodium and water excretion. This effect was not dependent upon the vasopressor action of vasopressin (V1 receptors), and, therefore, is probably attributable to a direct action on the kidneys via the renal nerves. Experiments are underway to test this hypothesis.

1. Schramm, LP, Strack, AM, Platt, KB, & Loewy,AD (1993) Brain Research, 616, 251.
2. Lovick, TA & Coote, JH (1988) Brain Research, 454, 123.
3. Lovick, TA & Coote, JH (1988) Journal of the Autonomic Nervous System, 25, 135.
4. Malpas, SC & Coote, JH (1994) American Journal of Physiology (Regulatory, Integrative, and Comparative Physiology, 266, R228.

HIV-1 TAT RELEASES INTRACELLULAR CALCIUM FROM IP_3-SENSITIVE POOLS IN CULTURED HUMAN FETAL NEURONS

Norman J. Haughey[1]*, Avindra Nath[2] and Jonathan D. Geiger[1]
Departments of Pharmacology[1] and Medical Microbiology/Internal Medicine (Section of Neurology)[2]
University of Manitoba, Winnipeg, MB., R3E 0W3, Canada.

Acquired Immune Deficiency Syndrome-related dementia complex is the commonest form of dementia in people less than 60 years of age. This subcortical dementia presents clinically as motor and cognitive deficits with no apparent correlation to viral burden. Post-mortum brain tissue clearly shows neuronal loss, but neurons are not infected by HIV; microglia and astrocytes are the primary cells infected. Neuronal destruction is therefore thought to occur by indirect mechanisms and implicated are the HIV-1 proteins gp120 and Tat (1,2).



Previously, we reported that the HIV-1 protein Tat_{1-86} was neurotoxic (3) and that a smaller length 30-mer Tat peptide, Tat_{31-61}, increased levels of intracellular calcium ($[Ca^{2+}]_i$) and decreased neuronal viability (4). Here we determined, using single cell calcium imaging, cultured human fetal neurons and pressure applied Tat_{1-72}, the extent to which Tat_{1-72}-induced increases in $[Ca^{2+}]_i$ originated from extracellular and intracellular sources. Tat_{1-72} (0.5 to 4.0 fmoles) increased $[Ca^{2+}]_i$ in human fetal neurons in a dose dependent manner (see accompanying figure). Maximal increases in $[Ca^{2+}]_i$ were observed at 4.0 fmoles; at higher doses Tat-induced increases in $[Ca^{2+}]_i$ went beyond the linear range of our Fura-2 calibration curve and resulted in a rapid loss of fluorescent signal. Tat_{1-72}-induced increases in $[Ca^{2+}]_i$ were specific because immunoelution with polyclonal anti-Tat significantly reduced calcium increases generated by 2.0 fmoles Tat_{1-72} (see table below). NMDA and non-NMDA type excitatory amino acid receptor blockers as well as removal of extracellular calcium were without effect on Tat_{1-72}-induced increases in $[Ca^{2+}]_i$ (data not shown). Tat_{1-72} induced increases in $[Ca^{2+}]_i$ were significantly attenuated by pretreatment with the inositol 1,4,5-trisphosphate (IP_3) agonist bradykinin, the IP_3 antagonist TMB-8, and the phopholipase C inhibitor neomycin.

Treatment	$[Ca^{2+}]_i$ Increase (nM)
Tat_{1-72}	254 ± 23
Anti-Ta	37 ± 6 ***
Neomycin (100 μM)	75 ± 17 ***
TMB-8 (100 μM)	48 ± 5 ***
Bradykinin (1μM)	29 ± 5 **

** indicates $p < 0.01$ / *** $p < 0.001$ (ANOVA)

Together, these results suggest that Tat_{1-72} increased the production of IP_3 and the release of Ca^{2+} from IP_3-sensitive intracellular pools in human fetal neurons. Tat-induced increases in $[Ca^{2+}]_i$ may be an early pathological event that culminates in neuronal death in HIV-1 infected individuals.

1. Dreyer, E.B., Kaiser, P.K., Offermann, J.T., Lipton, S.A. (1990) HIV-1 Coat Protein Neurotoxicity Prevented by Calcium Channel Antagonists, Science, 248; 364-367.
2. Sabatier, J., Vives, E., Makrouk, K., Benjouad, A., Rochat, H., Duval, A., Hue., Bahraoui, E. (1991) Evidence for Neurotoxic Activity of *tat* from Human Immunodeficiency Virus Type 1. J Virol. 65; 961-967.
3. Magnuson, D.S.K., Knudsen, B.E., Geiger, J.D., Brownstone, R.M., Nath, A. (1994) Human Immunodeficiency Virus Type 1 Tat Activates Non-N-Methyl-D-Aspartate Excitatory Amino Acid Receptors and Causes Neurotoxicity. Ann Neurol. 37; 373-380.
4. Nath, A., Psooy, K., Martin, C., Knudsen, B., Magnuson D.S.K., Haughey, N., Geiger, J.D. (1996) Identification of a Human Immunodeficiency Virus Type 1 Tat Epitope That is Neuroexcitatory and Neurotoxic. J. Virol. 70; 1475-1480.

N-ACETYLATION OF BENZIDINE BY RECOMBINANT HUMAN NAT1 AND NAT2 ACETYLTRANSFERASES

David W. Hein[1]*, Terry V. Zenser[2], Vijaya M. Lakshmi[2],
Timothy D. Rustan[1], Mark A. Doll[1], Anne C. Deitz[1], and Bernard B. Davis[2]
[1]Department of Pharmacology and Toxicology, University of North Dakota School of Medicine
and Health Sciences, Grand Forks, ND 58202-9037
[2]Veterans Affairs Medical Center and Department of Biochemistry and
Division of Geriatric Medicine, St. Louis University School of Medicine, St. Louis MO 63125-4199

Benzidine is an aryldiamine associated with the development of bladder cancer in occupationally exposed humans. Workers exposed to benzidine have as much as a 100-fold increased risk for urinary bladder cancer. Humans exhibit a genetic polymorphism in acetylation capacity that has been associated with increased incidence of urinary bladder cancer in workers exposed to aromatic amines. The classic acetylation polymorphism results from catalysis by a polymorphic *N*-acetyltransferase enzyme (NAT2) and results in rapid, intermediate, and slow acetylator phenotypes. A second *N*-acetyltransferase (NAT1) is regulated independently of the *NAT2* acetylation polymorphism. These studies were designed to assess metabolism of benzidine and *N*-acetylbenzidine by *N*-acetyltransferase isozymes NAT1 and NAT2. Metabolism was assessed using human recombinant NAT1 and NAT2 and human liver slices. For benzidine and *N*-acetylbenzidine, K_m and V_{max} values were higher for NAT1 than for NAT2. The clearance ratios (NAT1/ NAT2) for benzidine and *N*-acetylbenzidine were 54 and 535, respectively, suggesting that *N*-acetylbenzidine is a preferred substrate for NAT1. The much higher NAT1 and NAT2 K_m values for *N*-acetylbenzidine (1380 ± 90 and 471 ± 23 μM, respectively) compared to benzidine (254 ± 38 and 33.3 ± 1.5 μM, respectively) appear to favor benzidine metabolism over *N*-acetylbenzidine for low exposures. Determination of these kinetic parameters over a 20-fold range of acetyl-CoA concentrations demonstrated that NAT1 and NAT2 catalyzed *N*-acetylation of benzidine by a binary ping-pong mechanism. *In vitro* enzymatic data were correlated to intact liver tissue metabolism using human liver slices. Samples incubated with either [^{3}H]benzidine or [^{3}H]*N*-acetylbenzidine had a similar ratio of *N*-acetylated benzidines (*N*-acetylbenzidine + *N,N'*-diacetylbenzidine/benzidine) and produced amounts of *N*-acetylbenzidine > benzidine > *N,N'*-diacetylbenzidine. With [^{3}H]benzidine, *p*-aminobenzoic acid, a NAT1-specific substrate, increased the amount of benzidine and decreased the amount of *N*-acetylbenzidine produced, resulting in a decreased ratio of acetylated products. This is consistent with benzidine being a NAT1 substrate. *N*-Acetylation of benzidine or *N*-acetylbenzidine by human liver slices did not correlate with the *NAT2* genotype. However, a higher average acetylation ratio was observed in human liver slices possessing the *NAT1*10* compared to the *NAT1*4* allele. Thus, a combination of human recombinant *N*-acetyltransferase expression and liver slice experiments has demonstrated that benzidine and *N*-acetylbenzidine are both preferred substrates for NAT1. These results also suggest that NAT1 may exhibit a polymorphic expression in human liver.

Partially supported by USPHS grant CA-34627, USEPA grant R821836, and the Department of Veterans Affairs.

KNICKPOINT ANALYSIS OF STREAMS IN NORTH DAKOTA, SOUTH DAKOTA AND NEBRASKA

Trent D. Hubbard* and John R. Reid
Department of Geology /Geological Engineering, University of North Dakota, Grand Forks, ND, 58202

Previous workers have suggested the possibility of Pleistocene or more recent tectonic activity in south-central South Dakota and north-central Nebraska (1,2). A negative gravity anomaly exists in this area, which is reason to suspect such tectonic activity. The purpose of this study was to construct profiles along and in close proximity to several streams in this region (Bad R., White R., Keya Paha R., Ponca Creek), identify any irregularities and determine their possible causes. If recent tectonic activity has occurred evidence should exist in these profiles. Profiles were also constructed along and in close proximity to the Cannonball River in North Dakota as a comparison beyond the negative gravity area.

Data for the profiles were collected from 7.5 minute topographic maps as well as GPS surveys. Irregularities were determined by inspection of the profiles, as well as through spreadsheet calculation, in order to establish consistency between profiles. Profiles constructed along and in close proximity to streams in the study area contain numerous irregularities (Figure 1). In general, the profiles in close proximity to the streams (land surface profiles) show more irregularities than the stream profiles. This may be related to the method of construction of land surface profiles. Examination of the profiles has shown that some of the identified irregularities are the result of lithologic changes while others are the result of tributary streams. However, the reasons for many of the irregularities are not apparent and need to be field checked. Future work should also involve collection of more data through GPS surveying, which would increase the data base from which profiles can be constructed.

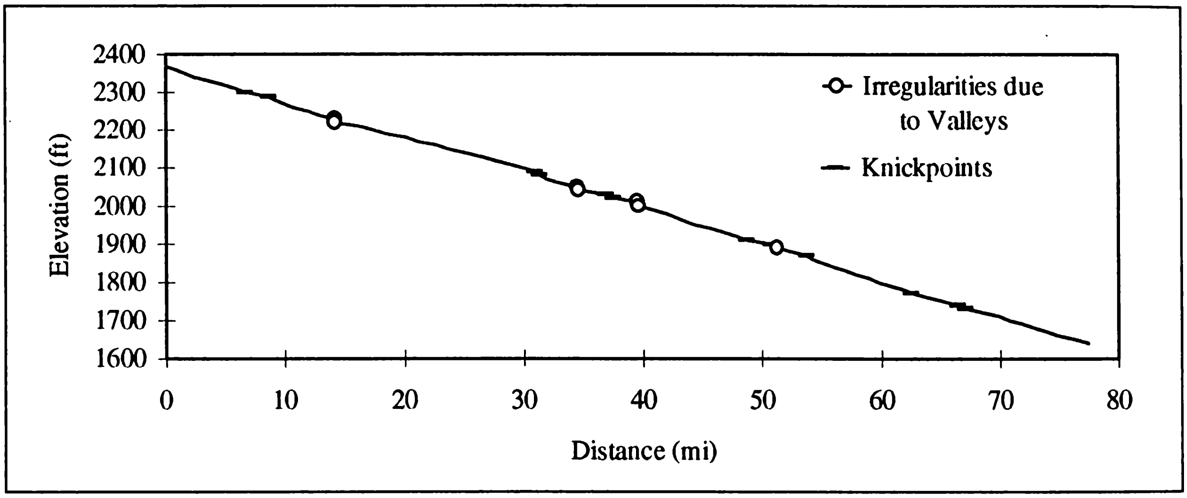


Figure 1. Keya Paha River Land Surface Profile C.

1. Nichols, T.C., Jr., Collins , D.S., Jones-Cecil, M., and Swolts, H.S. (1994) Faults and structure in the Pierre Shale, central South Dakota: *in* Shurr, G.W., Ludvigson, G.S., and Hammond, R.H., ed's (1994) Perspectives on the Eastern Margin of the Cretaceous Western Interior Basin. Boulder, Colorado, Geol. Soc. Amer. Spec. Paper 287, p. 211-35.

2. Shurr, G.W., Hammond R.H. ,Bretz, , R. H. (1994) Cretaceous Paleotectonism and postdepositional tectonism in south-central South Dakota : An example of epeirogenic tectonism in continental lithosphere: *in* Shurr, G.W., Ludvigson, G.S., and Hammond, R.H., ed's(1994) Perspectives on the Eastern Margin of the Cretaceous Interior Basin. Boulder, Colorado, Geol.Soc. Amer. Spec. Paper 287, p..237-56.

SEROTONIN UPTAKE BY BLOOD PLATELETS OF RATS IS REDUCED IN SEVERE, BUT NOT MARGINAL DIETARY IRON DEFICIENCY

Janet R. Hunt* and Carol Ann Zito
USDA, ARS, Grand Forks Human Nutrition Research Center, Grand Forks, ND 58202

Blood platelets have been proposed to model the central nervous system in neurotransmitter uptake and binding. Platelet serotonin uptake is consistently reduced in depressed patients (1). We investigated platelet serotonin uptake as a possible functional marker relating iron deficiency to mood and behavior.

The effects of deficient or marginal dietary iron on platelet serotonin receptor kinetics were tested in three experiments with Sprague-Dawley rats. All 3 experiments involved 11 to 16 young male rats per dietary treatment, with initial mean body weights of 80-100 g. Experimental diets that were formulated according to AIN-93G specifications (2), but modified in iron content, were fed for 7-10 wk. Platelet serotonin uptake kinetics were determined by incubating 0.05 to 1.0 μM ^{14}C-labeled 5-hydroxytryptamine (serotonin) with 8×10^7 platelets/mL, at 37° C with and without imipramine inhibition of active transport, for 2.25 m in an automated cell harvester. Other chemical methods have been described (3).

Diets containing less than 5 mg iron/kg produced severe iron deficiency characterized by anemia, depleted liver iron, and lower body weight (see table, experiments 1 and 3). With this severe iron deficiency, both the K_t and J_{max} of serotonin transport into platelets were decreased (see table). Diets containing 16-17 mg iron/kg resulted in marginal iron deficiency with low liver iron and slightly lower hematocrit without overt anemia, but did not affect body weight (see table, experiments 2 and 3). The kinetics of platelet serotonin uptake were unaffected by this marginal iron deficiency (see table).

Dietary iron (mg/kg diet)	Final body weight (g)	Hematocrit (%)	Liver nonheme iron (μmol/g dw)	Serotonin uptake, K_t (μM)	J_{max} (pmol/10^7 plt/m)
Experiment 1					
3 (deficient)	300*	24.8*	1.0*	0.122	7.96*
82 (adequate)	360	46.6	6.6	0.131	9.07
(Pooled SD)	(32)	(1.5)	(0.9)	(0.018)	(0.99)
Experiment 2					
16 (marginal)	359	45.5*	2.3*	0.121	4.12
86 (adequate)	368	47.2	7.5	0.126	4.58
(Pooled SD)	(27)	(2.0)	(1.8)	(0.022)	(1.04)
Experiment 3					
1.4 (deficient)	285*	19.7*	0.9*	0.089*	4.98*
17 (marginal)	375	50.4	2.6*	0.113	6.16
93 (adequate)	373	51.6	7.3	0.107	6.40
(Pooled SD)	(35)	(2.0)	(0.8)	(0.023)	(0.92)

**Significantly different than animals in the same experiment with greater dietary iron, $p < 0.05$.*

The results suggest that both the maximal rate of uptake and the serotonin concentration that results in half maximal uptake of number and affinity of serotonin in platelets are reduced by severe iron deficiency, but are unaffected by marginal iron status. These results may be useful in further investigation of the effects of severe iron deficiency. However, platelet serotonin uptake measurements apparently are not useful in the investigation of the possible psychological effects of marginal iron deficiency.

1. Wirz-Justice, A. (1988) Experientia 44, 145-152.
2. Reeves, P.G., Nielsen, F.H., and Fahey, G.C. (1993) J Nutr 123, 1939-1951.
3. Hunt, J.R., Zito, C.A., Erjavec, J., and Johnson, L.K. (1994) Am J Clin Nutr 59, 413-418.

CORONARY BLOOD VESSEL DEVELOPMENT WITHIN THE EPICARDIUM OF THE EMBRYONIC QUAIL HEART

David H. Hyjek* and Mark D. Olson
Department of Anatomy and Cell Biology, UNDSMHS, Grand Forks, ND 58202

Little is known concerning origins of vascular precursors and associated regulatory mechanisms involved in intramural coronary vessel vasculogenesis occurring within the epicardium of the embryonic vertebrate heart. This process occurs at the external surface of the myocardium within the connective tissue space of the epicardium known as the subepicardial space. This process appears to derive from reciprocal tissue interactions between the myocardium, dorsal mesocardium (a mesentery which suspends the embryonic heart within the pericardial cavity) and the continuous epicardium (1,2). It has been suggested that this vasculogenic event is induced by proteins secreted by the early myocardium since it and the surrounding subepicardial space immunostain with ES1, a polyclonal antibody which labels myocardial-derived secretory proteins which are known to induce endocardial endothelial activation within the atrioventricular canal of the embryonic chick heart (3).

The epicardium is the outer and final layer of the embryonic heart wall to develop. It originates from and is continuous with the dorsal mesocardium and migrates over the entire external surface of the myocardium by 4.5 days in both chick and quail embryos. The epicardium consists of a surface epithelium (mesothelium) and an underlying subepicardial space which is continuous with the connective tissue space of the dorsal mesocardium. *In situ* coronary vasculogenesis occurs from various cellular precursors within the subepicardial space. Endothelial precursors appear to derive from both mesenchyme which migrates from the continuous connective tissue space of the dorsal mesocardium, and from the overlying epicardial epithelium by means of epithelial-mesenchymal transitions (transformations). Endothelial precursors can be immunostained with QH1, a monoclonal antibody which specifically labels endothelial cells and their precursors (4). Through the use of QH1 conjugated with peroxidase (brightfield light microscopy), FITC, TRITC (fluorescent light microscopy) or colloidal gold (transmission electron microscopy [TEM]) it has previously been shown that endothelial precursors are present within the subepicardial space and overlying epicardial epithelium. The latter suggests that these endothelial precursors are derived, in part, from the epicardial epithelium. The current study, in the embryonic quail heart, utilizes monoclonal antibodies against cytoskeletal proteins (anti-cytokeratin and anti-vimentin) conjugated to either FITC or peroxidase to further elucidate the epithelial origin of certain endothelial precursors. The results indicate that subpopulations of endothelial cell precursors within both the epicardial epithelium and the subepicardial space label with QH1 and the above antibodies against specific cytoskeletal proteins. The data support the hypothesis that certain endothelial cells are derived from the epicardial epithelium since they possess unique epithelial-derived cytoskeletal proteins (cytokeratin) which are not found in migratory mesenchyme. Further evidence for the derivation of putative endothelial precursors from the overlying epicardial epithelium will be provided with TEM to demonstrate cells of the epicardial epithelium with morphology characteristic of epithelial-mesenchymal transitions.

1. Olson, MD, DL Bolender and RR Markwald (1989) Origins of coronary vessel precursors. Anat. Rec., 223:85A.
2. Olson, MD (1991) Morphogenesis of the heart wall. In: The Development and Regenerative Potential of Cardiac Muscle. Ed. by JO Oberpriller, JC Oberpriller and A. Mauro. Harwood Academic Publishers, New York, pp.. 53-79.
3. Krug, EL, RB Runyan and RR Markwald (1985) Protein extracts from eary embyonic hearts initiate cardiac endothelial cytodifferentiation. Dev. Biol., 112: 414-426.
4. Pardanaud, LC, P Altmann, F Kitos, F Dieterlen-Lievre and CA Buck (1987) Vasculogenesis in the early quail blastodisc as studied with a monoclonal antibody recognizing endothelial cells. Development, 100:339-349.

NATICID GASTROPODS (MOLLUSCA) AS PREY - AN EXAMPLE FROM THE FOX HILLS FORMATION (CRETACEOUS:MAASTRICHTIAN) OF NORTH AND SOUTH DAKOTA

Maureen A. Jones* and J. Mark Erickson
Department of Geology, St. Lawrence University, Canton, NY 13617

Predation is recognized as one driving force of evolution as predators evolved more efficient methods of securing prey and prey became more elusive or better armored to survive attack. Vermeij (1,2) has addressed evolution of gastropods as prey. Kitchell (3), Kelley and Hansen (4) have carefully examined the Naticidae as predators. A few studies have tested Vermeij's hypotheses of predation and escalation or dynamics of naticids as prey (5,6).

Since 1972, Erickson has been revisiting sites in the Fox Hills Formation that yield species of the naticid gastropod *Euspira* (7). Four localities in the Timber Lake Member have provided 283 specimens of *E. rectilabrum*, *E. subcrassa*, and *E. obliquata*. Two catergories of predation were recognized, shell breakage, seen as repaired breaks among normal growth lines or on the apertural lip, and borings or punctures of the shell. Vermeij (1) believed most shell repair to be due to predation attempts suggesting wave or storm damage does not occur to mollusks while living. We accept each repair as an instance of attempted molluscicide. Fox Hills naticids were prey for multiple durophagous predators. Peeling style breaks (1) suggest predation by calappid crabs such as *Necrocarcinus siouxensis* Feldmann and related crustaceans.

Taphonomic conditions varied from site to site. It was hoped that comparison of predation patterns between sites might permit identificaiton of niche, habitat, or behavioral differences between the three Fox Hills naticid species. Site A107 represents a high energy back barrier deposit; A131 a mid foreshore sand deposit; A141 and A114 are estuarine sand flat deposits with tidal channel influences. Site A131 (Figure 1) preserves the broadest size range of *E. subcrassa* and *E. rectilabrum*. Width measurements, grouped in 3-mm size classes, are used because maximum width of body whorl remains a valid comparison even if the aperture is partly broken or spire is eroded. Most individuals are preserved at A114 (N=112: *E. subcrassa* n=52, X=7.8 mm, SD=3.92; *E. rectilabrum* n=15, X=6.7 mm, SD=2.08; *E. obliquata* n=45, X=5.6 mm, SD=1.98), but the mean size is less than half that at A131 and approximately one third that of A141 (N=65: *E. subcrassa* n=48, X=12.4 mm, SD=4.42; *E. rectilabrum* n=9, X=9.6 mm, SD=0.85; *E. obliquata* n=8, X=8.9 mm, SD=1.6). A107 preserved only *E. rectilabrum* (N=28) in a broad size range with X=14.5 mm and SD=3.63. Widest size distribution s are for *E. subcrassa* which is the focus of predation data in Figure 2.

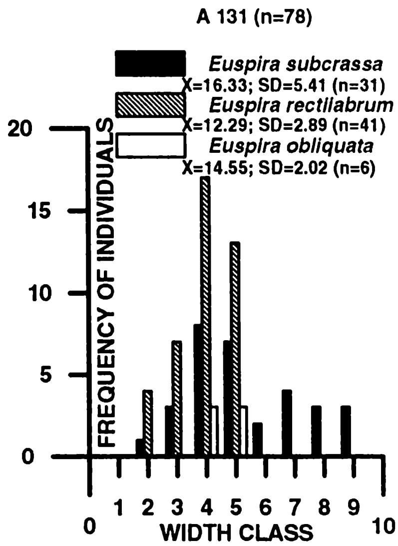


Figure 1: Size distributions for three *Euspira* spp. at site A 131. Compare these with mean breaks in Figure 2.

Mean predation attempts for each site and size occur in nearly direct proportion to specimen frequency of each species suggesting constant predation and taphonomic control by size sorting. *E. subcrassa*, the thickest-shelled species, diverges from this pattern by having increased attempts recorded on shells of classes 7 and 9 (20-29 mm) as individuals decrease in number suggesting the few individuals that grew to that size/ age survived a larger number of attacks. Above 20 mm *E. subcrassa* may have been in a partial refugium from these predators. Size classes 1 and 2 (8 mm or less) are scarce at all sites except A114 where the entire sample is of smaller naticids (X=6.7 mm). In this sample, size classes 1 and 2 show breaks distributed proportional to size frequency.

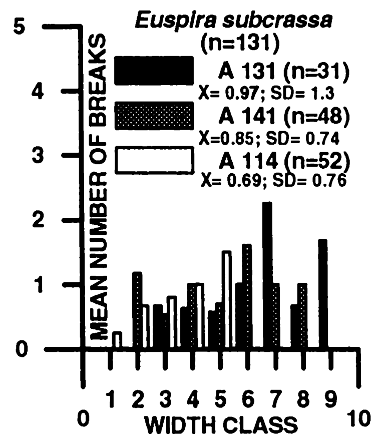


Figure 2: Mean number of breaks on *E. subcrassa* at three sites in the Fox Hills Fm.

1. Vermeij, G.J. (1977) Paleobiology 3, 245.
2. Vermeij, G.J. (1994) Annual Rev Evol and Syst 25, 219.
3. Kitchell, J.A. (1983) GSA Abstracts with Programs 15, 614.
4. Kelley, P.H. & Hansen, T.A. (1996) GSA Special Pub 102, pp. 373-386.
5. Roy, Kaustuv (1996) Paleobiology 22(3), 436.
6. Kabat, A.R. & Kohn, A.J. (1986) Palaeo. Palaeo. Palaeo 53, 255.
7. Erickson, J.M. (1974) Bulls American Paleo 66(284), pp. 131-253.

EFFECT OF MARGINAL AND MODERATE DIETARY COPPER DEFICIENCY ON TIBIAL GROWTH PLATE MORPHOLOGY IN THE WEANLING RAT CHALLENGED WITH INJECTED SHEEP RED BLOOD CELLS

Kay A. Keehr*, Joseph P. Idso, and Curtiss D. Hunt
USDA, ARS, Grand Forks Human Nutrition Research Center, Grand Forks, ND 58202

Severely copper-deficient animals and humans exhibit impaired osteogenesis and bone deformities. Infants and children consuming copper-deficient diets often exhibit bone abnormalities (1) even though newborn and very young children normally have a greater body copper content than do adults (2). We examined bone morphology in female weanling rats exposed to an immune challenge, and born to dams that were exposed to marginal and moderate copper deficiency during gestation and lactation. This experimental design modeled copper nutriture of nursing children (3) under mild but typical immunological stress.

During the 14-d habituation period, siring male and female (dams) Long-Evans rats of breeding age (90 days), were fed a basal diet (AIN-93G) (4) supplemented to contain an adequate amount of copper (6.0 mg Cu/kg). During gestation, dams were fed the basal diet supplemented with cupric carbonate to provide a total of 1.8 mg Cu/kg (G1.8) or 6.0 mg Cu/kg (control diet; G6.0) until parturition. During pup lactation, G1.8 dams were either switched to the basal diet providing a total of 0.9 mg Cu/kg diet (L0.9) or maintained on the same diet (L1.8); G6.0 dams remained on the same diet during lactation (L6.0).

On day 21, female pups were weaned, injected with sheep red blood cells (SRBC) and maintained on their respective lactation diets (P0.9, P1.8, or P6.0). On day 28, blood and liver samples were taken to assess copper status. The dissected right proximal tibiae were sectioned in the frontal plane to expose the epiphysial plate, fixed with buffered formalin and stained with Alcian blue. The heights of the proliferative (PZ), hypertrophic (HZ), and calcified (CZ) zones of the growth plate were determined at four selected sites (points interior to the medial and lateral edges of the epiphysial growth plate equal to 12.5 or 25% of the total plate width) by standard image analysis.

Table 1. Growth Plate Morphology and Indices of Copper Status in Female Weanling Rats Fed Marginally and Moderately Copper Deficient Diets

	Treatments (mg Cu/kg diet)			
Gestation	1.8	1.8	6.0	
Lactation and Postlactation	0.9	1.8	6.0	P-value
Ceruloplasmin, serum (mg/L)	45±10*(7)[1]	161±31*(7)	229±40(15)	0.0001
Cytochrome *c* oxidase, liver (nmol min^{-1}/mg protein)	76.7±21.3*(7)	88.9±16.5(7)	95.1±9.4(15)	0.04
Growth plate area (mm^2)	3.43±0.52(6)	3.20±0.16*(6)	3.60±0.22(14)	0.04
HZ height (mm), lat. side, 12.5% site	0.17±0.04(6)	0.15±0.02*(5)	0.19±0.03(14)	0.01
Total growth plate height (mm), lat. side, 12.5% site	0.68±0.06(7)	0.64±0.05*(5)	0.73±0.06(15)	0.02

*Significantly different than Diet 6.0 value, P<0.05 [1] Reported Mean±SD (n)=number of animals

Compared with the control group (G6.0/L6.0/P6.0), the marginal (G1.8/L1.8/P1.8) and moderate (G1.8/L0.9/P0.9) copper deficient groups exhibited progressively reduced copper status as indicated by progressive decreases in serum ceruloplasmin concentrations, an indicator of copper status (5) (Table 1). Hepatic cytochrome *c* oxidase activity, a less sensitive indicator (5) was lowest in the G1.8/L0.9/P0.9 group. One week after SRBC injection, the concentrations of serum ceruloplasmin, an acute-phase reaction protein (6), were similar to those reported earlier (5) in rats of similar age not challenged with injected SRBC. Measured indices of growth plate development did not follow the pattern of the measured indices of copper status. Instead, marginal copper deficiency altered growth plate morphology with recovery occurring under conditions of increased copper deficiency at least under concurrent conditions of immunological challenge. This finding indicates that bone metabolism is vulnerable to relatively small decreases in copper status. The finding also indicates a considerable insensitivity of copper homeostatic control mechanisms in that relatively large decreases in dietary copper are needed to stimulate copper homeostatic mechanisms to sufficiently protect the structure of rapidly growing bone.

1. Olivares, M. and Uauy, R. (1996) Am J Clin Nutr, 63 (5), pp 791S-796S.
2. Davis, G. K. and Mertz, W. (1987) in Trace Ele Hum Anim Nutr, 5th edition, 1, 10, pp 301-364. Academic Press, Inc, CA.
3. Vaquero, MP. and Navarro, M.P. (1996) Reprod Nutr Dev, 36, pp 333-344.
4. Reeves, P.G., Nielsen, F.H. and Fahey Jr., G.C. (1993) J Nutr, 123, pp 1939-1951.
5. Johnson, W.T, Dufault, S.N. and Thomas, A.C. (1993) Nutr Res, 13, pp 1153-1162.
6. Danks, D.M. (1981) Am J Clin Nutr, 34, pp 278-280.

TRANSIENT OVEREXPRESSION OF CATALASE REDUCES SECRETORY INHIBITION BY HYDROGEN PEROXIDE BUT NOT ALLOXAN IN BTC6-F7 CELLS

P. M. Kralik*, B. Xu, P. N. Epstein
University of North Dakota Department of Pharmacology and Toxicology, Grand Forks, ND 58202

Low levels of free radical scavenging enzymes, such as catalase and SOD may make beta cells highly sensitive to free radicals. Previous experiments have attempted to raise beta cell catalase levels by adding purified catalase enzyme, catalase containing liposomes or catalase coupled to polyethylene glycol. However, the efficacy of those methods is uncertain and the results are difficult to interpret. We have utilized alternative genetic approaches to increase catalase activity; transient transfection and transgenic mice. In this paper we describe the results obtained by transient transfection. They are consistent with the results we obtained in transgenic mice.

BTC6-F7 cells, an insulinoma derived beta cell line that maintains glucose responsive insulin secretion, were transfected with a catalase expression plasmid (INSCAT) or a control plasmid (INSPUC). The INSCAT gene increased catalase activity by more than 100 fold ($p< 0.01$). Cells were cotransfected with the human growth hormone gene to allow us to specifically measure secretion from transfected cells. Glucose response curves for growth hormone and insulin were very similar, indicating that growth hormone secretion provided a good marker for normal secretory function. To test the ability of elevated catalase enzyme activity to protect beta cell function, secretion was measured after exposure of cells to the beta cell toxins hydrogen peroxide (100 uM) and alloxan (10 mM). The percentage of control secretion remaining after toxin exposure was calculated and is shown in figure 1. Hydrogen peroxide inhibited hormone secretion down to 28% of control in cells tranfected with the control INSPUC plasmid but only down to 46% of control in cells transfected with the INSCAT plasmid. Therefore the catalase gene provided significant protection against hydrogen peroxide ($p<0.02$ INSPUC versus INSCAT). The effect of alloxan exposure was not significantly different between INSPUC and INSCAT transfected cells (figure 1 right). In summary, these results demonstrate two main points: 1. Cotransfection is a suitable method to test the protective effects of genes on sensitivity to free radicals and 2. Alloxan toxicity must be mediated by compounds in additon to hydrogen peroxide.

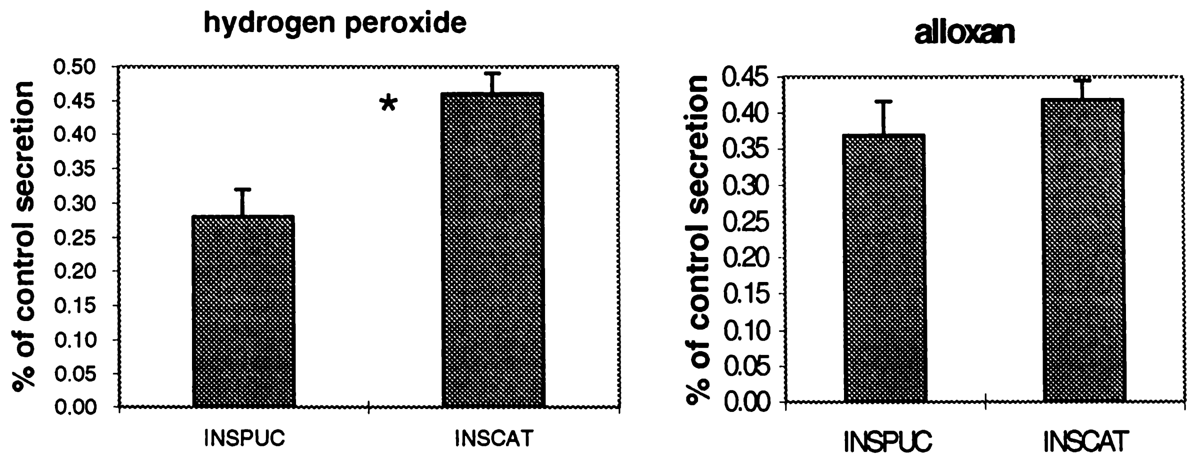


*Figure 1. Catalase protects against hydrogen peroxide (left) but not alloxan (right) in BTC6-F7 cells. Values are derived from at least four experiments performed in duplicate or triplicate. The * indicates p<0.02 by students t-test.*

EXPLANATION OF POOR PREDICTIONS OF BINDING OF SOME ANALOGS TO THE REGULATORY SUBUNIT OF CAMP DEPENDENT PROTEIN KINASE

Stephen L. Lowe[1]* and John B. Shabb[2]
[1]Dept. of Chemistry, Minot State University, Minot, ND 58707
[2]Dept. of Biochemistry and Molecular Biology, UND School of Medicine, Grand Forks, ND 58202

Protein kinases are well known for their roles in regulatory mechanisms in the cell; cAMP-dependent protein kinase is a tetrameric enzyme, R_2C_2, composed of two regulatory (R) and two catalytic (C) subunits. Binding four molecules of cAMP causes dissociation of the catalytic subunits which then become active. Two major regulatory subunit isoforms are known (RI alpha and RII alpha) and each has two cAMP binding sites (A and B) that have distinct analog specificities and kinetic properties (1). The X-ray crystal structure of the type I alpha R subunit has been determined (2). There are also cGMP-dependent protein kinases homologous with the cAMP dependent protein kinases which differ in their cyclic nucleotide-binding specificities.

As part of an effort to better understand the molecular basis of the differences in the specificities of these protein kinases we have made extensive use of analog binding data from the literature to create databases for performing quantitative structure-activity relationships (QSAR's) and comparative molecular field analyses (CoMFA's). These QSAR's and CoMFA's were performed on a Silicon Graphics Indigo work station using the programs known as SYBYL (Tripos) and INSIGHT II (Biosym/Molecular Simulations). Preliminary results of these studies have been presented (3).

Producing QSAR's and CoMFA's requires building a database of molecular structures in reasonable conformations in a common alignment. The database is then used to create a molecular spreadsheet containing binding data; CoMFA data of steric and electrostatic fields around each molecule is generated and, as the final step, a partial least squares analysis is performed to produce the QSAR and the CoMFA map. Binding data from Ogreid et al. (1) for eighty analogs were used. In our preliminary studies the torsion angle between the purine ring and the ribosyl moiety was set at the actual angle found for cAMP in the B-site of RI (-51.54°); further work was performed to modify the database using analog conformations minimized to conform to the known structure of the binding pocket to produce more interpretable CoMFA maps (4).

Below are some results with and without two analogs which consistently did not fit the model:

Binding Site	**X-validated r^2**	**Opt. # comp.**
AI: From preliminary study (3)		
All analogs / **without: 8-aza(OH), cXMP**	.499/ **.677**	4/ **4**
BI: From preliminary study (3)		
All analogs/ **without: 8-aza(OH), cXMP**	.297/ **.555**	4/ **5**
BI: Using analogs minimized in the B-site (8-aza(OH)cAMP not included)		
78 analogs +cXMP/ **without cXMP**	.489/ **.571**	4/ **4**

The X-validated r^2 is a measure of the reliability of the model for prediction of binding from the structure. Values of r^2 greater than approximately 0.4 are considered to have some predictive value; values greater than 0.7 are considered good.

The fact that omission of two analogs, 8-aza(OH)cAMP and cXMP, from our models consistently produced dramatic improvements in cross-validated r^2's lead us to examine their structures more closely and to compare their preferred conformations to those preferred by the binding sites.

Measurements of energy as a function of torsion angle for cAMP in the RIA binding site showed the minimum energy to be at a torsion angle (defined using C2'-C1'-N9 and C4) of -54°; for the RIB site the minimum was at -68° . These angles correspond to the *syn* conformation and deviations from these angles by more than 15° carries a prohibitive energy penalty.

The structure of cXMP was unique among all the analogs in our database in that it was the only one with a hydrogen at N3 of the purine ring; energy minimization of cXMP yielded a structure with a torsion angle of -110° and stabilized by a H-bond between the N3 hydrogen of the purine and the ribosyl ring oxygen.

Finding minimum energy conformations for 8-azaOHcAMP required performing simulated annealing runs. In this procedure the simulated molecule is heated to 1000K to overcome energy barriers so that a random search for minimum energy conformations can be made. The results of a 100 cycle search produced four families of conformers. The largest (31 members) and lowest energy cluster had torsion angles from +63.5° to +79.4°; these are *anti* conformations and are stabilized by a single H-bond between the 8-hydroxy group and the ribosyl ring oxygen. There was a second group (8 members) of *anti* conformers of slightly higher energy with torsion angles from +48.7° to +49.4° with two H-bonds. There were two clusters of low energy *syn* conformers of which only one (with 19 members) had torsion angles in a range to allow binding to the regulatory subunit; even these have about 2 kcal/mol higher energy than the main cluster of *anti* conformers.

Support for this work was provided by ND EPSCoR ROA grants to SLL and by NIH grant R29GM49848 to JBS.

1. Ogreid, D., Ekanger, R., Suva, R., Miller, J., Doskeland, S. O. (1989) Eur J Biochem 181: 19-31
2. Su, Dostmann, Herberg, Durick, Xuong, Ten Eyck, Taylor, and Varughese (1995) Science 269: 807-813
3. Lowe, S.L., Muhonen W., Shabb, J.B. (1996) Proc of the North Dakota Academy of Science 50: 51
4. Shabb, J.B., Muhonen, W. and Lowe, S.L. (1996) Protein Science 5, Suppl. 1, 97

APOPTOSIS IN VENTRICULAR MYOCYTES OF THE ADULT NEWT

Dawn K. Mersch*, John T. McCormack and Jean C. Oberpriller
Department of Anatomy and Cell Biology, University of North Dakota SMHS, Grand Forks, ND 58202

Ventricular myocytes of the adult newt Norophthalmus viridescens respond to injury or stress by proliferation to a degree that is more intense than in any other normal adult heart system. This response has been studied in vivo with direct ventricular injury and in vitro (1). Periods of intense proliferation in some systems, particularly in development, may be accompanied by apoptosis or programmed cell death, which allows an organism to remove cells that are defective or detrimental to the system without inducing an inflammatory process. Recently, there has been evidence that the binucleation seen in late cultures of newt cardiac myocytes may be the beginning of aberrant mitotic activity in which resulting daughter cells vary in their nuclear makeup. Disruption of cellular components, which appears to occur in binuclear or multinuclear division in cultured newt cardiac myocytes, may trigger apoptosis so that the system can rid itself of the outcome of terminal aberrant mitotic division of binucleated or multinucleated cells.

Transforming growth factor-beta (TGF-beta) is a potent inhibitor of DNA synthesis in cultured newt cardiac myocytes, with the number of tritiated thymidine labeled myocytes decreased to 38.3% of controls. It has been reported by Tsukada et al. (2) that TGF-beta can induce apoptosis and also down-regulate *bcl-2* expression, which is the gene that controls inhibition of apoptosis. Heparin is also a potent inhibitor of DNA synthesis and mitosis in the cultured cardiac myocyte, decreasing the rate of DNA synthesis to 31.5% of control cultures. No significant connection between heparin and apoptosis has been reported. It is appropriate to determine the incidence of apoptosis in newt cardiac myocytes which have been placed in culture. The influence of known proliferative inhibitors (TGF-beta and heparin) on the process of apoptosis in the culture system will also be clarified.

Ventricles of adult newt were surgically removed and the cardiac myocytes were dissociated using a trypsin/collagenase mixture. The isolated cells were placed into culture using previously reported methods (3). Cultures were fed on days 5, 7, 9 and 11 with Leibovitz L-15 medium, modified by dilution to 70% and supplemented with 10% fetal bovine serum. Experimental cultures were fed on the same days with standard medium supplemented with TGF-beta (Collaborative Research, 1 ng/ml) or heparin (Sigma, 50 µg/ml). All cultures were fixed on day 12 in 10% neutral buffered formalin. Fixed cultures were then subjected to immunoassay, using an in situ detection kit (Oncor Apoptag), which utilizes digoxigenin to tag the DNA fragments formed as the end product of apoptosis. An anti-digoxigenin antibody conjugated to peroxidase was added and the specimens were stained with substrate to allow visualization of the apoptotic end products in the cells. Positive staining controls involved pretreatment of specimens by nicking DNA with DNA-ase I. Negative staining controls involved elimination of the terminal deoxynucleotidyltransferase from the staining protocol, preventing the addition of digoxigenin-nucleotide to the DNA. Isolated myocytes fixed and observed on the day of dissociation showed no peroxidase labeling indicative of apoptosis. Some degree of apoptosis (5.17%) was evident at 12 days in culture, which is the time of peak proliferative activity in the system. When cultures were treated with TGF-beta (1ng/ml) and fixed at 12 days, the number of myocytes undergoing apoptosis was significantly ($p < 0.001$) elevated (16.8% $\pm$ 1.4), equivalent to 325% of control levels. Correspondingly, treatment with heparin (50µg/ml) and fixation at 12 days resulted in a significant ($p < 0.001$) elevation in the degree of apoptosis in cardiac myocytes (13.1% $\pm$ 1.72), equivalent to 253% of control levels. These results indicate that apoptosis may be a factor in the control of proliferative outcomes in the cardiac myocyte culture system. It will be important to complete a time course study with regard to apoptotic activity in the cultures at pre- and post-proliferative periods. The strongest inhibitors of proliferation in these cultures, TGF-beta and heparin, appear to stimulate apoptosis in the myocytes. While the mechanism for action of TGF-beta has been suggested to be a down-regulation of genetic control of apoptotic inhibition in other systems, there is no specifically known mechanism for the apoptotic response seen in heparin-treated cells. It will be important to learn if this stimulation of apoptosis is more or less intense in older cultures in which there appear to be more aberrant cells resulting from the proliferative process.

1. Oberpriller, J.O., Oberpriller, J.C., Matz, D.G. and Soonpaa, M.H. (1994) Ann NY Acad Sci 752:30-46.
2. Soonpaa, M.H., Oberpriller, J.O. and Oberpriller, J.C. (1992) J Molec Cell Cardiol 24:1039-1046.
3. Tsukada, T., Eguchi, K., Migita, K., Kawabe, Y., Kawakami, A., Matsuoka, N., Tatashima, H., Mizokami, A. and Nagataki, S. (1995) Biochem Biophys Res Commun 210:1076-1082.

THE EFFECTS OF MATERNAL ETHANOL CONSUMPTION ON THE LIVER OF THE DEVELOPING RAT FETUS

Meyers, AFA[1]*, Casiro OG[2], Minuk, GY[1]
[1]Liver Diseases Unit, Departments of Medicine and Pharmacology and [2]Paediatrics,
University of Manitoba, 820 Sherbrook Street Winnipeg MB Canada R3A 1R9

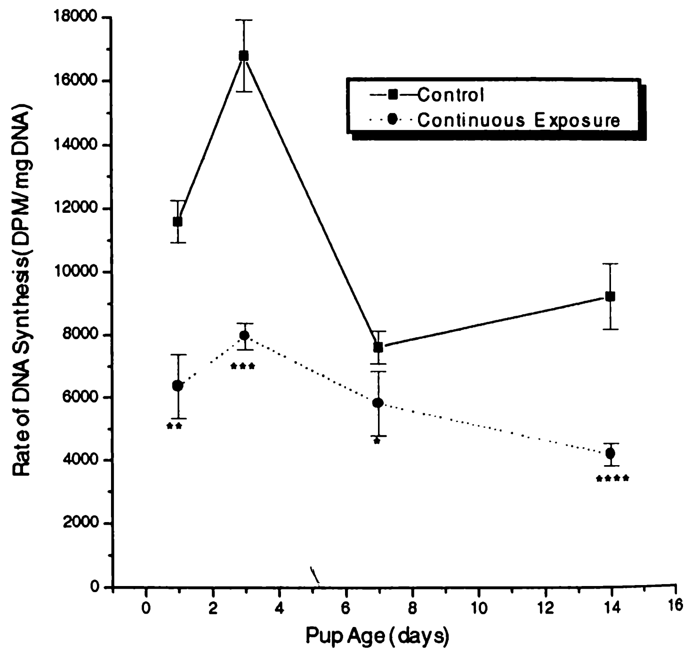
The inhibitory effects of alcohol on hepatic growth in adults raises the possibility that the liver may be involved in the Fetal Alcohol Syndrome (FAS) of infants. To test this hypothesis, pregnant Sprague-Dawley rats were fed a liquid diet containing ethanol as 36% of the total calories or an isocaloric liquid (controls) throughout pregnancy. In additional experiments designed to determine the critical time of exposure to alcohol for liver development, ethanol administration was limited to early (first trimester) or late (last trimester) stages of pregnancy. Pups delivered of dams exposed to ethanol throughout pregnancy (n=45), early pregnancy (n=28), late pregnancy (n=19), and controls (n=43) were sacrificed at 1, 3, 7, and 14 days of age. As demonstrated in the accompanying table and figure, the experimental results revealed that pups exposed to ethanol throughout pregnancy had significantly lower liver/body weight ratios ($p<0.05$) on days 7 and 14 of age, and rates of DNA synthesis ($p<0.05$) at all time points when compared to controls. The ethanol fed pups also failed to thrive and differences in liver/body weight ratios became more pronounced during the first two weeks of life. Regarding early versus late ethanol exposure, no inhibitory effects on liver growth or development were observed in either group at any time interval.

Table I: The effects of ethanol throughout pregnancy on neonatal liver/body weight ratios

Study Group	Age (days)	Liver/ Body Wt. Ratio (x ± sem)
Control n=11	1	0.0403 ± 0.002
Ethanol n=6	1	0.0400 ± 0.002
Control n=12	3	0.0374 ± 0.001
Ethanol n=6	3	0.0400 ± 0.001
Control n=12	7	0.0329 ± 0.001
Ethanol n=6	7	0.0289 ± 0.001*
Control n=6	14	0.0362 ± 0.001
Ethanol n=6	14	0.0264 ± 0.001*

*p<0.05 versus controls

Figure I: Rates of DNA synthesis in pups born to mothers who consumed ethanol throughout pregnancy and controls.



*p<0.05, **p<0.005, ***p<0.001, ****p<0.0005

In conclusion, these results indicate that in this animal model: 1) the liver is a significant component in the constellation of alcohol - related birth defects, 2) hepatic DNA synthesis is impaired, 3) catch - up liver growth does not occur, and 4) early or late exposure to ethanol during the gestational period do not have the inhibitory effects on liver growth and development as does exposure throughout the gestational period.

COPPER DEFICIENCY AND SUPPLEMENTATION IMPACT THERMOREGULATION AND BROWN ADIPOSE TISSUE (BAT) MITOCHONDRIAL MORPHOLOGY OF RATS EXPOSED TO COLD

KG MICHELSEN*; CB HALL; SM NEWMAN, Jr; HC LUKASKI
USDA/ARS Grand Forks Human Nutrition Research Center, Grand Forks, ND 58202.

Non-shivering thermogenesis (NST) plays a major role in the maintenance of body temperature in mammals during acute cold exposure. One site of this process occurs in the mitochondria of BAT and utilizes the uncoupling of oxidative phosphorylation to produce heat. At this site thermoregulation occurs through an interaction between thyroid hormone metabolism and the sympathetic nervous system. Copper-deficient (CuD) rats have impaired NST when acutely exposed to cold air and decreased circulating thyroid hormones. The morphological changes in mitochondria in BAT resulting from CuD are not well studied. Therefore, two studies were designed to examine BAT mitochondrial morphology in conjunction with body temperature regulation and thyroid hormones.

In both studies (I and II), male weanling Sprague-Dawley rats were matched by weight and fed purified diet either adequate in copper (CuA, >5 ppm; n=21&12) or deficient in copper (CuD,<0.5 ppm; n=32&24) for 4 wk. At 4 wk, each CuD group was matched by weight into two other treatment groups. One group remained on the CuD diet for 5 d, while the second group was placed on the CuA diet for 5 d (CuS). A thermistor was surgically implanted intraperitoneally to monitor the body temperature (T_B) of each animal in Study I. The animals were fasted overnight then half of the rats in each dietary group were exposed to 4°C for 4 h and the other half were maintained at room temperature (RT 27°C). After decapitation, cervical blood was collected and prepared for either hematology or plasma thyroxine (T_4) and triiodothyronine (T_3) measurements. Liver mineral analysis was performed in both studies. Ultrastructural examination of BAT was performed in Study II. Dissected BAT was fixed in 3% phosphate buffered glutaraldehyde (pH=7.3), post-fixed in 1% OsO_4 then dehydrated in ethanol. The BAT was embedded in Embed-812. Thin sections were studied by using a transmission electron microscope.

Copper-deficient rats in Study I showed signs of deficiency: anemia, lowered ceruloplasmin and increased cholesterol concentrations (Table 1). In contrast to the CuA and CuS, the CuD rats did not have a significant increase in plasma T_3 or T_4 concentration and had a significantly more rapid decrease in T_B (ΔT_B) during cold exposure (Table 2).

Table 1. Hematocrit (Hct), Hemoglobin (Hgb), Ceruloplasmin (Cp) and Cholesterol (Chol) Concentrations (mean ± SD)

	Cu A		Cu D		Cu S	
	RT	4°C	RT	4°C	RT	4°C
Hct[A], l	0.45 ± 0.01	0.45 ± 0.01	0.26 ± 0.01	0.29 ± 0.01	0.38 ± 0.01	0.36 ± 0.01
Hgb[A], g/L	151 ± 4	148 ± 3	80 ± 5	90 ± 5	123 ± 4	116 ± 4
Cp[A], mg/dL	57.8 ± 3.4	59.1 ± 3.5	5.4 ± 5.2	5.6 ± 5.2	34.0 ± 4.8	33.3 ± 4.3
Chol[B], mg/dL	134 ± 14	147 ± 14	212 ± 21	209 ± 21	140 ± 20	146 ± 18

[A]CuA>CuS>CuD, $p<0.001$ [B]CuD>CuA and CuS, $p<0.05$

Table 2. Thyroid Hormone Concentrations and T_B (mean ± SD)

	Cu A		Cu D		Cu S	
	RT	4°C	RT	4°C	RT	4°C
T_3[A], nmol/L	0.94 ± 0.09	1.56 ± 0.09	0.80 ±0.14	1.06 ± 0.14	0.87 ± 0.13	1.41 ± 0.12
T_4[A], nmol/L	62 ± 4	104 ± 4	55 ± 6	66 ± 6	61 ± 6	95 ± 5
ΔT_B[A], °C/h	-0.004 ± 0.001	0.005 ± 0.001	-0.022 ± 0.004	-0.542 ± 0.003	0.001 ± 0.001	-0.015 ± 0.002

[A]Diet and Temperature interaction, $p<0.05$

Micrographs from BAT of each animal in study II were used for several characterizations. Mitochondria were scored from one to five: 1 is towards orthodox (crista folds were non-distended) and 5 is condensed (moderate increases in crista distention). In the condensed state mitochondria show a greater use of oxidative phosphorylation for ATP production than do those in the orthodox state. Lipid content was assessed by counting the number of grid hits on lipid per cell profile (NGHL/C). Regardless of the diet consumed, the mitochondrial configuration index (Mito. Index) shifted toward the orthodox configuration and the number of grid hits on lipid decreased upon cold exposure (Table 3).

Table 3. BAT Mitochondrial Index and Lipid content (mean ± SD)

	Cu A		Cu D		Cu S	
	RT	4°C	RT	4°C	RT	4°C
Mito. Index[A]	2.65 ± 0.51	2.24 ± 0.21	3.14 ± 0.29	1.77 ± 0.70	2.80 ± 0.94	2.37 ± 0.34
NGHL/C[B]	31 ±13	9 ± 6	25 ± 8	4 ± 5	33 ± 12	2 ± 1

[A]Diet and Temperature Interaction, $p<0.008$ [B]Temp effect, $p<0.001$

These mitochondrial changes imply that CuD rats at RT rely to a greater extent on oxidative phosphorylation for ATP production than do CuA or CuS rats. Also, the shift away from oxidative phosphorylation during cold exposure in CuD rats is significantly greater than in CuA or CuS rats. These findings indicate that CuD results in impaired thermoregulatory function and altered BAT mitochondrial morphology and cell lipid content. Short-term supplementation of CuD rats with Cu ameliorates the anemia, low ceruloplasmin concentration and hypercholesteremia. Supplementation also restored thyroid hormone and lipid status needed to promote NST. Mitochondrial configuration reverted to a more normal state in rats that were repleted.

AGE-RELATED CHANGES IN SCLERAL PROTEOGLYCANS

Bobbie A. Mount* Virginia R. Achen and Jody A. Rada
Department of Anatomy & Cell Biology, University of North Dakota
School of Medicine & Health Sciences, Grand Forks, ND 58202.

Scleral proteoglycans were characterized from human donor eyes of ages 7 months to 94 years in order to identify age-related changes in the synthesis and/or accumulation of scleral proteoglycans. Sclera were dissected into anterior, equatorial, and posterior regions. Glycosaminoglycans were extracted from each sample with guanidine hydrochloride (GuHCl) and quantified using dimethylmethylene blue to measure total sulfated glycosaminoglycans. Scleral proteoglycans in anterior, equatorial and posterior regions of the sclera in young and old sclera were characterized by sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE) followed by selective staining of proteoglycans with alcian blue. The distribution of proteoglycans in the human sclera was evaluated by light microscopy following staining of scleral sections with alcian blue. To characterize newly synthesized proteoglycans, freshly obtained sclera were radiolabelled with $^{35}SO_4$ in organ culture for 24 hrs at 37°C. Scleral proteoglycans were extracted with 4M GuHCl and separated by molecular sieve chromatography on Sepharose CL-4B. The elution positions of newly synthesized and total accumulated proteoglycans were determined by assaying each fraction for radioactivity and sulfated glycosaminoglycans, respectively.

Age-related changes in total sulfated glycosaminoglycans present within the anterior, equatorial and posterior sclera were evaluated by regression analyses. Within the anterior sclera, total accumulated glycosaminoglycans decreased significantly from age 7 months to 94 years ($p = 0.005$), while no significant changes were seen in the glycosaminoglycan content in the posterior or equatorial sclera SDS-PAGE analyses indicated that three proteoglycans were present in each scleral region, although their relative concentrations varied with age and the region of the sclera. Examination of scleral sections stained for the presence of proteoglycans with alcian blue indicated that there was a loss of alcian blue-positive material from the anterior sclera of older (84 year old) sclera, while the posterior sclera demonstrated alcian blue staining similar to that of younger (1 month old) sclera. Newly synthesized and total accumulated human scleral proteoglycans were separated into three major peaks by chromatography. The first two peaks represented large proteoglycans related to aggrecan (the cartilage proteoglycan), whereas the third peak represented the small proteoglycans, biglycan and decorin (chondroitin/dermatan sulfate proteoglycans). Measurements of the areas under each peak of each chromatographic profile for all donors indicated that the relative percentages of newly synthesized proteoglycans in peaks 1 and 2 increased from 7 - 17% and 8 - 17% with increasing age (0.58 to 83 years), respectively ($p \leq 0.05$). Total accumulated proteoglycans in peaks 1 and 2 also increased from 9 - 25% and 12 - 31% with increasing age ($p \leq 0.04$). Newly synthesized and total accumulated proteoglycans in peak 3 decreased from 85 - 65% and 79 - 44% with increasing age, respectively ($p \leq 0.02$).

Conclusions. Aging is associated with a loss of total sulfated glycosaminoglycans from the anterior sclera, but not from the equatorial or posterior sclera. Three major proteoglycans are present in the human sclera but the relative amounts of each proteoglycan change with age. The large proteoglycans related to aggrecan are synthesized and accumulate in the aging sclera, while the relative percentage of the smaller proteoglycans biglycan and decorin decreases with increasing age. The presence of aggrecan-like proteoglycans in the aging sclera may be related to the scleral involvement which frequently accompanies rheumatic diseases such as rheumatoid arthritis and relapsing polychondritis.

Supported by a grant from NIH (EYO9391, JAR) as well as from the Howard Hughes Undergraduate Biological Science Education Program (BAM).

A DESCRIPTION OF THE FOSSIL FISH ASSEMBLAGE OF THE SENTINEL BUTTE FORMATION (PALEOCENE) NEAR ALMONT, NORTH DAKOTA INCLUDING TWO NEW SPECIES

M. G. Newbrey* and M. A. Bozek
Biology Department and Wisconsin Cooperative Fishery Research
Unit, College of Natural Resources, University of Wisconsin,
Stevens Point, WI 54481

We examined what appears to be the littoral zone of an ancient lake in the Sentinel Butte Formation (Paleocene), near Almont, North Dakota to assess the fish fauna of the site. The site, known primarily for semitropical terrestrial plant fossils (1), has a fish assemblage similar to a fish assemblage in the Paskapoo Formation (Paleocene) in Alberta, Canada (2) but with some taxonomic distinctions. We used meristic and morphological characteristics of nearly- and partially-complete fish specimens and disarticulated scales for taxonomic analyses.

There is evidence that at least seven species of fish occurred at this site. Fish identified to species include a pike (*Esox tiemani*) (Esocidae) and a bowfin (*Amia uintaensis*) (Amiidae). Fish identified to genus include a new species of fish (*Asineops sp.*) (Asineopidae). Fish identified to subfamily or family include an unidentified species of osteoglossid (Heterotidinae), a gar (Lepisosteidae) and a herring-like fish (Clupeidae). A few disarticulated scales represent still another unknown fish species of the superorder Osteoglossomorpha.

The pike (*Esox tiemani*), originally described from the Paskapoo Formation in Alberta, Canada (2), is known from the Sentinel Butte Formation by several different specimens. *Esox tiemani* specimens include a nearly complete juvenile, a large partial pectoral fin, a pair of dentaries, several patches of scales, and individual scales.

The bowfin (*Amia uintaensis*) found at this site is similar to bowfin found in the Green River Formation (Eocene) and reported from the Fort Union Group (Paleocene) of Montana (3). There are two partial specimens belonging to the North Dakota Geologic Survey and numerous *Amia uintaensis* scales in the collection at University of Wisconsin - Stevens Point attributed to this species. One rather large partial specimen displays scales and cliethra. The cliethra have a diagnostic 90° angle between the posterodorsal ramus and the anteroventral ramus similar to extant *A. calva* and extinct *A. unintaenses*, yet lacks the notch which is present ventral to the metacliethrum in *A. calva* (3).

The Almont *Asineops sp.* specimen appears to be a new species. The University of Wisconsin - Stevens Point has two incomplete specimens and the North Dakota Geologic Survey has one incomplete specimen. The Almont *Asineops* has some similarities to the valid extinct species *Asineops squamifrons* of the Green River Formation (Eocene). Similarities include scale dentition, principal anal fin ray count, and principal caudal ray count of 1-6-6-1 (4). However, the Almont *Asineops sp.* caudal vertebral count (greater than the 17 visible) is markedly different than *A. squamifrons* (13 to 15).

We also propose a new species, perhaps of the genus *Joffrichthyes* of the subfamily Heterotidinae. This fish resembles *Joffrichthyes symmetropterus* of the Paskapoo Formation in Alberta, Canada (5). The Almont fish has large pelvic fins and a triangle-shaped anal fin in which the standardized basal length is considerably less than the standardized dorsal fin length whereas the dorsal and anal fins are symmetrical on *J. symmetropterus*.

The Almont site also has produced two types of fish species that are in a private collection and unavailable for peer review. One is a new species of clupeid that resembles *Knightia sp.* but displays a different anal fin than *Knightia eocaena* of the Green River Formation (Eocene). The second fish is represented by a single patch of gar scales (family Lepisosteidac).

Both the *Asineops sp.* and the Osteoglossid are currently being studied for taxonomic description and future work at the Almont site may reveal additional species.

1. Crane, P. R., Manchester, S. R., & Dilcher, D. L. (Dec. 1990) A preliminary survey of fossil leaves and well preserved reproductive structures from the Sentinel Butte Formation (Paleocene) near Almont, North Dakota. Fieldiana, Geology n.s. 20, Chicago, IL: Field Museum of Nat. Hist.
2. Wilson, M. V. H. (1980) Oldest known *Esox* (Pices: Esocidae), part of a new Paleocene teleost fauna from western Canada. Canadian Juornal of Earth Sciences 17:307-312.
3. Borske, J. R. (1974) A review of the North American fossil amiid fishes. Bull. Mus. Comp. Zool. Harv. 146:1-87.
4. Grande, L. (1984) Paleontology of the Green River Formation, with a review of the fish fauna. The Geologic Survey of Wyoming, Bulletin 3: 334pp. (2nd ed.)
5. Li G.-q and Wilson, M. V. H. (1996) The discovery of Heterotidinae (Teleostei: Osteoglossidae) from the Paleocene Paskapoo Formation of Alberta, Canada. Journal of Vertebrate Paleontology 16:198-209.

DIETARY FRUCTOSE AND MAGNESIUM AFFECT MACROMINERAL METABOLISM IN MEN

Forrest H. Nielsen* and David B. Milne
USDA, ARS, Grand Forks Human Nutrition Research Center
Grand Forks, ND 58202

Since the introduction of high-fructose corn sweeteners in 1967, per capita consumption of fructose has increased markedly in the United States. It has been estimated that fructose consumption accounts for more than 10% of the total energy intake of United States citizens, and some intakes, especially those of heavy consumers of soft drinks, probably approach 15% of dietary energy (1). Another common occurrence among United States citizens is the consumption of diets that supply significantly less than the recommended dietary allowance for magnesium. Studies with rats have found that an interaction between dietary fructose and magnesium affects macromineral metabolism in rats (2). High dietary fructose significantly increased kidney calcium in female rats fed deficient or adequate magnesium diets, and in male rats fed the magnesium-deficient diet only; the greatest kidney calcification occurred in female rats fed the high fructose, magnesium-deficient diet. Thus, an experiment was performed with men between the ages of 22 and 40 years housed in a metabolic ward to ascertain whether an interaction between fructose and magnesium affects macromineral metabolism in humans. Eleven men participated in four dietary periods of 42 days in which dietary magnesium was either approximately 170 or 370 mg/day, and dietary fructose was either 4% or 19% of energy. A decaffeinated carbonated beverage containing high fructose corn syrup replaced cornstarch, bread and rice in the low fructose diet to give the high fructose diet. The protein from the high starch foods was replaced by egg-white protein. The treatments were randomized so that 2 to 3 individuals were on each treatment during each 42 day period. Serum and urine variables were determined by our usual standard methods (3).

Table 1. Effect of Dietary Magnesium and Fructose on Calcium, Magnesium and Phosphorus Balance, and on Serum Alkaline Phosphatase in Men.

Dietary Treatment		Magnesium*	Calcium*			Phosphorus*			Alkaline
Magnesium mg/d	Fructose* %energy	balance mg/d	Diet mg/d	Urine mg/d	Balance mg/d	Diet mg/d	Urine mg/d	Balance mg/d	phosphatase** u/L serum
165	4	-14	1151	236	180	1455	962	62	88
370	4	29	1160	248	143	1464	948	71	90
175	19	2	1010	229	71	1522	1171	-50	95
369	19	52	1012	231	107	1502	1114	-10	97
Analysis of Variance -P Values									
Magnesium		0.0001		0.29	1.00		0.07	0.43	0.45
Fructose		0.01		0.08	0.007		0.0001	0.005	0.005
Magnesium x fructose		0.64		0.40	0.14		0.25	0.62	0.94
Pooled SD		23		20	79		60	99	7

*Average per day over the complete 42-day period.
**Values from the last 28 days of each dietary period.

As shown in Table 1, dietary fructose significantly affected magnesium, calcium and phosphorus balances. With the low fructose diet (high starch), when dietary magnesium was about 170 mg/day, magnesium balance was -14 mg/day; because this value is markedly lower than when dietary magnesium was 370 mg/day (29 mg/d), an intake of 170 mg/d is probably inadequate for men consuming a high starch diet. Although high fructose improved magnesium balance, it depressed calcium balance with the effect more marked when dietary magnesium was low. High dietary fructose also decreased phosphorus balance and increased the concentration of alkaline phosphatase in plasma. These findings indicate that dietary fructose affects macromineral metabolism in humans. Further studies are warranted to see if a high fructose diet with low dietary magnesium and marginal calcium leads to bone loss.

1. Park, Y.K., Yetley, E.A. (1993) Am J Clin Nutr 58(suppl), 737s-747s.
2. Koh, E.T., Min, K.-W. (1991) Magnesium Res 4, 97-103.
3. Nielsen, F.H., Hunt, C.D., Mullen, L.M., and Hunt, J.R. (1987) FASEB J 1, 394-397.

SEARCHING FOR THE LAST DINOSAUR....A SYSTEMATIC SURVEY IN THE LATEST CRETACEOUS ROCKS OF SOUTHWESTERN NORTH DAKOTA

Dean A. Pearson*
Paleontology Department, Pioneer Trails Regional Museum, Bowman, N. Dakota 58623

A systematic survey was undertaken to determine the stratigraphic position of the youngest dinosaur fossils in sedimentary rocks of southwestern North Dakota. The results describe patterns of dinosaur distribution in the latest Cretaceous rocks of this area, but they may also be utilized as a proxy for the latest Cretaceous elsewhere.

Of primary concern was to test the hypothesis that the highest 2-3 meters of Cretaceous rocks are virtually barren of fossils (1, 2). For this study, only the uppermost three meters of the Hell Creek and the lowermost few meters of the overlying Ludlow Formation were surveyed. The lithologically determined formational contact (sometimes refered to as the "basal coal") has recently been demonstrated to be diachronous (3, 4, 5); and the Cretaceous-Tertiary (K-T) boundary may occur in the Hell Creek or in the Ludlow Formation. Therefore, Brown's formula (6) for determining the position of the Cretaceous-Tertiary (K-T) boundary is invalid and all previously described occurrences of dinosaurian remains relative to this boundary are dubious. Determination of a specimen's position relative to the K-T boundary must be based upon palynological or other high resolution methods to be valid.

The highest stratigraphic occurence of dinosaurian remains located during this survey are in the Ludlow Formation at Locality V96019. The specimen consists of an *in-situ* ceratopsian dinosaur including frill, rib fragments, and a brow horn in a light brown, silty mudstone 81 cm above the Hell Creek/Ludlow formational contact. The lithologic contact was identified at the base of the lowest laterally persistant lignite which forms a break in hill slope. The palynologically defined K-T boundary has not yet been precisely defined at this site, but preliminary results indicate the boundary to be between 59 and 142 cm above the specimen (K.R. Johnson and D.J. Nichols, pers. comm. 1996).

The presence of a partial ceratopsian skeleton in the uppermost 2 meters of Cretaceous rocks in North Dakota indicates that dinosaurs existed within this previously described "2-3 meter gap" below the K-T boundary and therefore survived until the very end of the Cretaceous. Their previously reported absence was probably an artifact of insufficient collection activity.

The apparent slow or step-like decline in dinosaur diversity from the Campanian to the Maastrichtian has been used to support a gradual or stepwise extinction hypothesis (7, 8) as opposed to a mass extinction at the K-T boundary (9, 10). It is possible that a Campanian impact coupled with the K-T boundary Chicxulub impact could have acted as a "one-two punch" on dinosaurs. The Manson impact site in Iowa occurred at approximately 74 ma (11) and an impact at this time could have caused major extinctions in the abundant dinosaur fauna found in the Judith River Group. The location of the Manson impact site in the central part of North America allows for it to have had a direct, or indirect impact on the survivability and diversity of Judithian/Edmontonian dinosaurs. The development of new species (i.e. Tyrannosaurus, Triceratops, Torosaurus, and Edmontosaurus) seen in the Hell Creek Formation could have occurred during the time between the two impacts. These species could have been thriving during the Maastrichtian only to be exterminated by the terminal Cretaceous impact event.

1. Williams, M. (1994) Journ Paleontology 68 (2) pp183-190
2. Williams, M. (1994) Journ Paleontology 68 (5) p 1168
3. Johnson, K.R. and Hickey, L.J. (1990) GSA Special Paper 247 pp 433-444
4. Fastovsky, D. (1990) GSA Special Paper 247 pp 541-548
5. Johnson, K.R. (1992) Cretaceous Research 13 pp 91-117
6. Brown, R.W. (1962) Geol Survey Prof Paper 375 pp 1-119
7. Sloan , R.E. and et al. (1986) Science 232 pp 629-633
8. Archibald, J.D. (1987) Mem Soc Geol France New Series 150 pp 45-52
9. Alvarez, L.W. (1983) Nat Acad Science 80 pp 627-642
10. Sheehan, P.M. and et al. (1991) Science 254 pp 835-839
11. Anderson, R.R, Witzke, B.J., and Hartung, J.B. (1996) GSA Special Paper 307 pp 527-540

EXPRESSION OF GELATINASE A (MMP-2) IN THE SCLERA OF CHICK EYES DURING THE INDUCTION AND RECOVERY OF FORM DEPRIVATION MYOPIA

C.A. Perry*, M. Slover, S. Laducer and J.A. Rada
Department of Anatomy & Cell Biology, University of North Dakota
School of Medicine & Health Sciences, Grand Forks, ND 58202.

We have previously shown that during the development of experimental myopia (form deprivation myopia in chicks), there is a significant increase in latent gelatinase activity in the posterior sclera (1). Chemical assays suggest that the increase in gelatinase activity is due, in part, to an increased amount of the 72 kDa gelatinase proenzyme (gelatinase A, or MMP-2) within the posterior sclera. The current study examines the distribution and relative expression of gelatinase A (MMP-2) mRNA within the posterior sclera of form deprived (myopic) eyes, control eyes, and eyes recovering from form deprivation myopia, in order to better understand the regulation of gelatinase activity within the chick sclera. Form deprivation myopia was induced in chicks for 2-10 days by the application of a translucent occluder to one eye. Following 10 days of form deprivation, recovery was established by removing the occluder followed by 1-5 days of normal visual experience. Total RNA was extracted from the posterior sclera of chicks at several points during the period of form deprivation and during the recovery periods and subjected to northern blot analyses using a cDNA probe to a conserved region of MMP-2. The MMP-2 cDNA probe was generated by reverse transcription polymerase chain reaction (RT-PCR) from total chick scleral RNA, using primers selected based on the published sequences for human, rat and mouse MMP-2. The RT-PCR product was cloned into PCR-script and cDNA probes were generated from the cloned insert by random primer extension. An RNA probe specific for a region of human 18S rRNA was used on the same blots following removal of the previous probe to standardize for loading variation. The distribution of MMP-2 mRNA was evaluated by in situ hybridization on frozen sections of chick sclera using ^{33}P-labeled sense and antisense RNA probes generated from the PCR-script clone using T7 and T3 RNA polymerase.

Northern blot analyses indicated that the MMP-2 cDNA probe hybridized to a 3.3kB band in control sclera, form-deprived sclera and recovering sclera. Densitometric evaluation of northern blots indicated that following 10 days of form deprivation the relative expression of MMP-2/18S rRNA was increased by 76% in deprived eyes as compared to controls, whereas following 1 day of recovery, levels were decreased by 73% in sclera from recovering eyes as compared to controls ($p \leq 0.05$, see figure 1). In situ hybridization experiments indicated that MMP-2 is expressed primarily in the fibrous scleral layer with only minimal expression being found in the cartilaginous scleral layer.

Conclusions. Changes in levels of expression for MMP-2 mRNA within the fibrous layer of the chick sclera during the induction and recovery from form deprivation myopia correlate with previously observed changes in gelatinase activity and are likely to be involved in the scleral remodeling processes associated with ocular elongation and the development of myopia in a variety of species.

Supported by a grant from NIH (EYO9391, JAR).

1. Brenza, H.L. and Rada, J.A. (1995) Invest Ophthalmol Vis Sci 36, 1555.

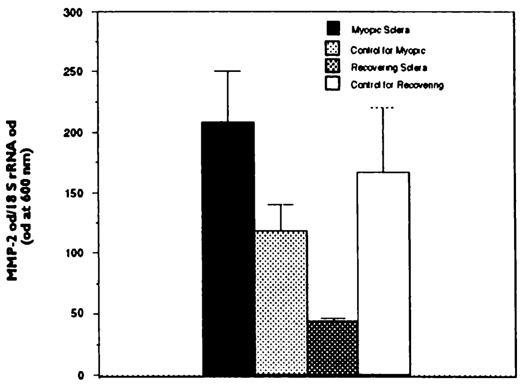


Figure 1. MMP-2 Expression in Myopic, Control and Recovering Sclera

TEMPORALLY-REGULATED GENE EXPRESSION IN EMBRYONIC RAT THORACIC SPINAL CORD REVEALED BY DIFFERENTIAL DISPLAY

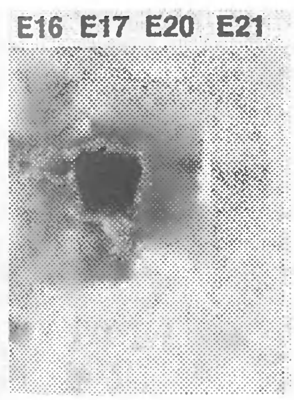
Wendy Perryman*, Yuri McKee, Cheryll Perry, Jody Rada, and Kenneth Ruit
Department of Anatomy & Cell Biology, University of North Dakota School of Medicine and Health Sciences, Grand Forks, ND 58202

Recent experimental approaches to the study of gene expression in the developing spinal cord have demonstrated the presence of neurotransmitters, growth factors and guidance cues that appear either at discrete times early in development or for extended periods of time throughout prenatal development and even into the postnatal period McConnell (1).

Based on some remarkable morphologic observations we have made in the developing rat thoracic spinal cord related to a population of autonomic motor neurons Ruit & McKee (2), we are presently interested in identifying genes in the embryonic spinal cord that are expressed at very discrete developmental time points late in embryonic development (during the last prenatal week). While many known genes are expressed either at discrete times early in development or for extended periods of time later in development and even into postnatal life, our hypothesis is that potentially unknown genes expressed at discrete times at later stages of prenatal development represent critical links in the chain of developmental processes necessary in establishing structural and functional diversity in the central nervous system, specifically the spinal cord.

In order to describe the temporal differences in the expression of genes in the rat thoracic spinal cord on days during the last prenatal developmental week, RT-PCR differential display was utilized. Total RNA was isolated from fresh-frozen isolated embryonic spinal cords. The reverse transcription (RT) reaction was used to make copy DNA (cDNA) from the mRNA in the total RNA population. The amplified cDNA was then electrophoresed on a 6% polyacrylamide sequencing gel. After drying, autoradiography and band isolation was conducted. After the bands of interest were identified and isolated for reamplification, the cDNA probes were reamplified and cloned. After the plasmid was checked to contain the insert, a northern blot procedure was performed to verify the differentially displayed bands. Once northern blot verification of the differentially displayed bands was concluded, nucleotide sequencing of the differentially displayed probes began. All sequence and homology comparisons were verified using the Basic Local Alignment Search Tool (BLAST) database.

All experimental data were analyzed qualitatively using strict experimental control and procedural verification protocols. Preliminary observations comparing total mRNA from the thoracic spinal cords of embryonic day 17 (E17) and embryonic day 20 (E20) rats demonstrated a number of differentially displayed bands. Five differentially displayed bands were chosen, isolated and cloned. The majority of these differentially expressed bands were found at E17 and not at E20. One of the genes that we have chosen to work with further has been designated 17A2". The differentially displayed 17A2" was verified using the northern blot procedure to test the probe and its control 18S rRNA probe. The northern blot revealed that the 17A2" gene was indeed differentially expressed; expression of 17A2" was considerably reduced in E16, E20 and E21 embryos (figure at left). Since 17A2" was found to be differentially expressed, the next objective was to determine its nucleotide sequence. Using BLAST, a homology comparison was undertaken. The genetic sequence was found to have 86% homology with the human mitochondrial elongation factor (MEF) gene. MEF has been shown to regulate protein synthesis by mitochondrial ribosomes. The significance of MEF in the embryonic rat spinal cord is still considered unknown and will continue to be investigated by our laboratory.



We hypothesize that potentially unknown genes expressed at discrete times at later stages of prenatal development represent critical links in the chain of developmental processes necessary in establishing structural and functional diversity in the spinal cord. The utilization of current very powerful molecular techniques has allowed us to begin to identify, isolate, and understand the function of genes that are only expressed during very short, defined periods of time during the final postnatal week. We believe it is important to gain an understanding of neural developmental processes late in embryogenesis because, in many respects, the nervous system has assumed its adult structure by the day of birth. Because of this, we hypothesize that developmental processes that occur later in development may be those that can be more readily re-initiated clinically in order to create an environment conducive to regeneration and repair following spinal cord injury.

1. McConnell, S.K. (1995) The Journal of Neuroscience 15, 6987.
2. Ruit, K.G. and McKee, Y.F. (1993) Society for Neuroscience Abstracts 19, 1713.

NEUROTOXIC MECHANISMS OF ALZHEIMER'S Aβ1-42 PROTEIN FRAGMENT

Garl K. Rieke* and Katie Jacobson
Department of Anatomy and Cell Biology
School of Medicine and Health Sciences
University of North Dakota, Grand Forks, ND 58202

The Alzheimer precursor protein (APP) is a highly conserved integral membrane protein in many different cells including neurons of diverse species. The processing of APP is of intense interest as genetic errors in the structure of APP leading to over-production of the precursor and its catabolites may be an underlying cause of Alzheimer's Disease (AD). Aβ1-42 is a normal catabolic product of the Alzheimer precursor protein; however, evidence indicates that this 42 amino acid fragment is the neurotoxic peptide in AD. Neurons in culture and brain areas including the septum/diagonal band, hippocampus and the cortex are destroyed when challenged with Aβ1-42. This neurotoxic fragment triggered apoptosis.

Secreted Aβ1-42 may interact with receptors on the cell surface as a step in its neurotoxicity. Rieke and associates (1) have shown that the neurotoxicity of Aβ1-42 is markedly attenuated by the NMDA receptor antagonist AP-5 (2-amino-5-phosphonovaleric acid) or Mg^{+2}. Male Sprague-Dawley rats (195-250 grams) were individually anesthetized with sodium pentobarbital [40 mg/Kg ip] and positioned into a Kopf model 1407 stereotaxic instrument. Under sterile surgical conditions a stainless steel cannula was stereotaxically implanted into the dorsal hippocampus, according to the coordinates from the rat atlas of Pellegrino, et. al. (2). The cannula (Alzet brain infusion kit) was coupled to an osmotic pump (Alzet model 2004) by a short section of tubing and the assembly was placed into 0.9% sterile saline at 37°C for 10 hrs to provide the pump an adequate start-up time. The pumps were filled with Aβ1-42 (0.22 ηmol/μL), AP-5 (0.22ηmol/μL or $MgCl_2$ (1.5 mM). Aβ1-42 was coinjected with the competitive NMDA antagonist (AP-5) or the non-competitive antagonist $MgCl_2$. After ten days of intrahippocampal delivery of test compounds, the rats were sacrifice by intracardiac perfusion with 4% paraformaldehyde. The brains were embedded in paraffin, serially sectioned, mounted on glass slides, stained and examined microscopically for evidence of drug-induced lesions in the hippocampus. The volume of the lesions induced by the NMDA antagonists alone were small, with minimal cell loss. In contrast the hippocampal lesions induced by challenge with Aβ1-42 were large with extensive loss of pyramidal cells and granule cells. Aβ1-42 induced apoptosis in many granule cells. The lesions were serially reconstructed and their calculated volumes revealed that the Aβ1-42 lesion volume was 9 times larger than the Aβ1-42/AP-5 lesion and 7 times larger than the Aβ1-42/Mg^{+2} induced lesions.

In conclusion, the neurotoxicity of Aβ1-42 is attenuated by antagonists of the N-methyl-D-aspartate (NMDA) excitatory amino acid receptor which is present at high density on neurons of the hippocampus (both pyramidal cells [Pry. cells] and granule cells [DG]). The attenuation of Aβ1-42 neurotoxicity suggests a possible interaction with the NMDA receptor. Our observations suggest that secreted Aβ1-42 may open the Ca^{+2} iontophore of nearby NMDA receptors and that Ca^{+2} influx acts to trigger the cascade of intracellular events which induce apoptosis in nerve cells of the hippocampus. Whether or not to use NMDA receptor antagonists as a therapeutic treatment in Alzheimer's Disease remains a thorny issue.

---

1. Rieke, G.K. and Jackobson, K. (1996) Soc. Neurosci. Abstr. 22,197.
2. Pellegrino, L.J., Pellegrino, A.S. and Cushman, A.J. (1979) A Stereotaxic Atlas of the Rat Brain, 2nd ed. Plenum Press, New York.

PHYSICOCHEMICAL AND BIOLOGICAL CHARACTERISTICS OF THE HYPORHEIC ZONE OF A NORTHERN PRAIRIE STREAM

D.B. Rush[1]*, P.J. Gerla[1], D.R. Goebel[2]
[1]Dept. Geology and Geo. Engineering, University of North Dakota, Grand Forks 58202
[2]Energy and Environmental Research Center, University of North Dakota, Grand Forks 58202

Potential lower boundaries and seasonal characteristics of the hyporheic zone of a first order stream were identified by examining the physical, chemical, and biological gradients in saturated sediments of the stream bed and riparian zones. In past studies by hydrologists and stream ecologists, streams have been viewed as pipes removing water and dissolved substances from a basin. Recent studies suggest that streams and their adjacent aquifers interact hydraulically either as an effluent stream being fed by ground water or as an influent stream contributing water to the aquifer (1). Along the length of a stream, ground and surface waters interact to a varying degree in what is called the hyporheic zone. This zone beneath streams is not well defined because of its dynamic nature. The position and chemistry of the hyporheic zone can fluctuate daily, seasonally or annually, and vary spatially along the length of the stream. Because of this dynamic nature, the hyporheic zone may act as a source or sink for dissolved solutes in the stream at different times (1). In addition, the hyporheic zone has been found to be inhabited by a host of fauna and flora which affect solute fate and transport. Amphibionts use the hyporheic zone during stages in their life cycle or to escape disturbances in stream discharge (2,3). Other fauna, or stygobionts, have been found only in the hyporheic zone or adjacent ground water environments (3).

The purpose of this interdisciplinary study was to characterize the hyporheic zone and detect its dynamic boundaries by: 1) locating changes or gradients in water chemistry in the sediments beneath and adjacent to the stream; 2) identifying populations of fauna inhabiting the zone; and 3) measuring hydraulic gradients and flow within the zone. In addition, the influence of cattle grazing on the dynamics of the hyporheic zone was considered.

On the Tongue River, west of Cavalier, ND, a site affected by cattle grazing and an undisturbed site upstream were instrumented with mini-piezometer nests 0,1, and 2 meters from the stream margin following procedures similar to those used by Patch and Padmanabhan (4). Nests of larger piezometers and water table wells constructed from 2.54 cm PVC were installed at variable distances in the riparian zone using standard procedures. The mini-piezometers (1.27 cm polyethylene tube) were screened at 10, 35, 60, 85, 100, 150, and 200 cm below the stream bed, and the larger piezometers were screened at approximately 50, 100, and 150 cm below the June water table. Screen length on all piezometers was 10 cm. Water samples collected every three weeks were analyzed for electrical conductivity (EC), pH, redox potential (Eh), dissolved oxygen, and temperature in the field, and NO_3^- and NH_4^+ in the lab. Field chemistry measurements were made in a sealed, flow-through cell. Nitrate and ammonia were measured in the lab with ion selective electrodes.

Fauna samples were collected twice during the study from variable depths beneath the bed and stream margin using a cased standpipe with a stainless steel screened point. Up to five liters of formation water were pumped from the point and passed through a 63 µm sieve, rinsed into a sample bottle, stained with rose bengal, and preserved with a 10% buffered formalin solution. In the lab, fauna was separated from the sediment by swirl decantation and manual separation under 40x magnification. Preliminary sorting has revealed copepods, ostracods, and nematods.

Anaerobic conditions exist directly below the stream bed at both locations. Nitrate levels peaked in spring, with concentrations as high as 220 µg/L, and decreased through the summer. Ammonia levels increased during the summer in the deeper marginal sediments, suggesting some nutrient storage. Ammonia concentrations and EC were elevated at the grazed site (>10 mg/L and 1300 µS, respectively). EC and reduction potential increased immediately below the stream, then decreased laterally and with depth. Hydraulic conductivity estimates ranged from 0.01 to 20 m/day, with the highest conductivities occurring between 60 and 85 cm below the stream bed at both sites.

Abrupt chemical, biological, and physical discontinuities were not present for most of the parameters measured, although EC and Eh gradients could be used to distinguish hyporheic water from true ground water. Hydraulic conductivity gradients may indicate a boundary layer between the hyporheic zone and the adjacent aquifer, but no correlation could be made between hydraulic conductivity and chemical attributes of the formation water. Upper boundaries of the hyporheic zone are difficult, if not impossible to determine due to the gradual chemical and physical gradients present. Lower boundaries appear more abrupt, possibly due to the geomorphic characteristics of the stream bed sediments. Direct deposition of nitrogenous waste may be responsible for high levels of ammonia in the shallow sediments of the grazed site, however further study will be necessary before a direct connection can be implied.

The authors wish to gratefully acknowledge Henry Duray, Icelandic State Park, and the Hinkle family for granting access to the study sites and their assistance during the project. Funding for this project was provided in part by Sigma Xi, North Dakota Academy of Science, and the Energy and Environmental Research Center.

1. Bencala, K. E. (1993) Journal of the North American Benthological Society 12(1), 44-47.
2. Resh, V. H. , A. V. Brown, A. P. Covich, M. E. Gurtz, H. W. Li, G.W. Minshall, S. R. Reice, A. L. Sheldon, J. B. Wallace, and R. C. Wissmar. (1988) Journal of the North American Benthological Society 7(4), 433-455.
3. Stanford, J. A. and J. V. Ward. (1993) Journal of the North American Benthological Society 12(1), 48-60.
4. Patch, J. C. and G. Padmanabhan. (1994) Water Resource Investigation 31, pp 25-28. North Dakota State Water Commission, Bismarck.

ACCELERATED CARDIOLIPIN METABOLISM IN A CHINESE HAMSTER LUNG FIBROBLAST CELL LINE DEFICIENT IN OXIDATIVE ENERGY PRODUCTION

Alison Rusnak, Rick Mangat*, Fred Xu, Grant McClarty and Grant M. Hatch
Department of Pharmacology and Therapeutics,
Faculty of Medicine, University of Manitoba, Winnipeg, MB, Canada, R3E 0W3

Cardiolipin was first discovered in 1942 by Mary Pangborn in the isolated bovine heart (1). In mammalian tissues the majority of cardiolipin is associated with the mitochondrial inner membrane (2) and it is synthesized in the mitochondria via the cytidine-5'-diphosphate-1,2-diacyl-sn-glycerol (CDP-DG) pathway (3). Cardiolipin is required for the functioning of several important mitochondrial enzymes involved in oxidative phosphorylation such as cytochrome c oxidase (4). In our study we have investigated the cardiolipin metabolism characteristics of a Chinese hamster lung fibroblast cell line CCL16-B2, deficient in oxidative energy metabolism.

Cardiolipin *de novo* biosynthesis was examined by measuring the activities of the enzymes in the CDP-DG pathway in CCL16-B1 (B1) and CCL16-B2 (B2) cells. Enzyme assay analysis revealed that there was no difference in microsomal phosphatidic acid: cytidine-5'-triphosphate (PA:CTP) cytidylyltransferase activity in B2 compared to B1 cells. As a consequence microsomal PA:CTP cytidylyltransferase activity served as a control for an enzyme not affected by the mutation in B2 cells. However, mitochondrial PA:CTP cytidylyltransferase activity, cardiolipin synthase activity and conversion of glycerol-3-phosphate and CDP-DG to cardiolipin was found to be elevated in B2 cells compared to B1 cells. These results implied that there was an initial increase in cardiolipin biosynthesis.

To investigate the *de novo* biosynthesis of cardiolipin from glycerol, cells were incubated with [1,3-^{3}H]glycerol for up to four hours and the radioactivity incorporated in cardiolipin determined. The radioactivity incorporated into cardiolipin in B2 cells was decreased by thirty percent compared to B1 cells when incubated for the same length of time. Interestingly, radioactivity incorporated into phosphatidylglycerol (PG), the immediate precursor of cardiolipin was increased 2.5 fold by 120 min of incubation in B2 cells compared to B1 cells. The elevation in radioactivity incorporated into PG may be explained by the increase in mitochondrial PA:CTP cytidylyltransferase observed in the *in vitro* analysis. In contrast, the increased *in vitro* cardiolipin synthase activity in B2 compared to B1 cells indicates that the decreased amount of radioactivity incorporated into cardiolipin observed in the glycerol labeling studies was not due to a decreased conversion of PG to cardiolipin.

Further studies of the B1 and B2 cells cardiolipin fatty acid species demonstrated variations in the level of certain unsaturated but not saturated fatty acids. The percent of palmitoleic (16:1) and oleic acid (18:1) were reduced and the percent of linoleic acid (18:2) was elevated in B2 compared to B1 cells. *In vivo* cardiolipin resynthesis from [1-^{14}C] palmitate (16:0) was elevated indicating elevated cardiolipin resynthesis.

The results of this study clearly demonstrate a variation in cardiolipin metabolism in CCL16-B2 cells. Since a specific cellular cardiolipin content and molecular species composition is required for oxidative energy production we propose that the reduction in oxidative energy production in CCL16-B2 cells may be attributed to the alteration of the cardiolipin molecular species composition observed in B2 cells.

1. Pangborn, M.C. (1942) J Biol Chem 143, 247-256.
2. Stoffel, W. and Schiefer, H.G. (1968) Hoppe-Seyler's Z Physiol Chem 349, 1017-1026.
3. Kiyasu, Y., Pieringer, R.A, Paulus, H, Kennedy, E.P. (1963) J Biol Chem 238, 2293-2298.
4. Hatch, G.M. (1996) Mol Cell Biochem 159, 139-148.

SMALL MAMMAL HABITAT ASSOCIATIONS IN A WESTERN MINNESOTA GRAVEL QUARRY

Lowell E. Schmitz, Jamie L. Stegeman*,
and Donna M. Bruns Stockrahm
Department of Biology, Moorhead State University
Moorhead, MN 56563

Western Minnesota has some of the last remnants of tallgrass prairie in the United States. Because the area was formerly occupied by glacial Lake Agassiz, this same general area has many sand/gravel quarries. In Clay County, Minnesota, preserves of tallgrass prairie are often in close proximity to the quarries which offer ecologically-interesting habitat mosaics.

As part of a larger study, four study plots in Clay County, Minnesota, were live-trapped for small mammals during the summer of 1995 with emphasis on habitat use and community structure in a western Minnesota gravel quarry. The quarry consisted of open, sandy areas with interspersed grasslands. We implemented a 10-by-10 trapping grid scheme with 10 m between traps along a transect and 10 m between transects for a total of 100 traps per plot. Traps were generally set at sunset and checked beginning at sunrise for 4 consecutive days. Small mammal species, sex, age, weight, reproductive condition, toe-clip number, and location of capture were recorded for each animal.

Habitat data were measured and recorded at each trap station. Vegetation density and height, ground cover composition, and litter type and depth were recorded. Percents of ground cover comprosed of the four categories of grass, forbs, litter, and bare ground were estimated within a circle with a diameter of 1 m. Topography, soil type and moisture, and main plant species were described.

Six rodent species, i.e., meadow voles (Microtus pennsylvanicus), prairie voles (M. ochrogaster), deer mice (Peromyscus maniculatus), northern grasshopper mice (Onychomys leucogaster), meadow jumping mice (Zapus hudsonius), and thirteen-lined ground squirrels (Spermophilus tridecemlineatus) were captured. Three shrew species, i.e., arctic (Sorex arcticus), masked (S. cinereus), and shorttail shrews (Blarina brevicauda) were captured.

Habitat data were compared for the different small mammal species using a variety of analyses including ANOVA, Duncan's multiple-range tests, and regressions. Although results differed somewhat between the four study plots, statistical differences ($P<0.05$) in habitat associations were noted between the species. Meadow voles and meadow jumping mice were usually associated with greater vegetation densities. However, meadow voles used areas with a greater percent of grass cover while meadow jumping mice used areas with greater forb cover. Deer mice used areas with significantly less vegetation density and significantly more bare ground than nearly all of the other species. Meadow and prairie vole habitats generally did not differ significantly ($P>0.05$) from each other regarding vegetation density, litter depths, and ground cover. However, prairie voles seemed to be associated with little bluestem (Andropogon scoparius) whereas meadow voles used nearly any type of available grassy cover. Very few northern grasshopper mice were captured, thus the statistical analysis is not reliable. However, they utilized areas with disturbed soils and early-successional plant species with sparse vegetation density at the plant base.

We thank The Minnesota Chapter of The Nature Conservancy and the Minnesota Nongame Wildlife Tax Checkoff for their financial support.

COMPARISON OF METHODS OF ESTIMATING BODY COMPOSITION CHANGES DURING WEIGHT LOSS IN WOMEN

W.A. Siders* and H.C. Lukaski
USDA, ARS, Grand Forks Human Nutrition Research Center, Grand Forks, ND

While caloric restriction can decrease body weight, changes in the components of the body are important factors for consideration in planning weight loss programs. Although body composition assessments can be made by using a number of methods, there is little information on the sensitivity of common methods to track changes in body composition during weight loss. This study compared body composition determinations from four methods over four months of controlled weight loss in obese women.

Thirty women, age 21-39 years, participated in 150-day metabolic studies of reduced energy intake (50% of weight maintenance) and supervised exercise (2 hr/d) at the Grand Forks Human Nutrition Research Center. The studies started with a 30 day baseline period during which energy requirements to maintain body weight were determined. At the end of the baseline period, the subjects had a body mass index of 35.9 ± 5.1 (mean ± standard deviation) kg/m^2, a body volume of 101.6 ± 17.5 L, and a total body water volume of 38.6 ± 4.7 L.

Body composition was assessed (during baseline period and each month thereafter) by four common methods: anthropometry (ANC), two forms of hydrostatic densitometry (HDC) with simultaneous determination of underwater weight and lung volume (1), and dual X-ray absorptiometry (DXA). Durnin & Wormersely (2) prediction formulae were used with ANC measurements. HDC measurements were merged with deuterium dilution total body water assessments (3) to use the prediction formulae of Siri (3) with (HDC-W) and without (HDC) corrections for body water. Enhanced Whole Body Software - Version 5.54 was used with DXA. Duplicate meals and urine, feces and menses were analyzed in 6-day collection periods to determine daily N_2 balance (intake - elimination). Results of the assessments are summarized in Table 1.

Table 1. Body Weight and Composition Changes (Mean ± standard deviation)

	Baseline	30 days	60 days	120 days
Body Weight, kg	99.9^{A} ± 16.0	96.6^{B} ± 15.4	90.0^{C} ± 14.6	81.9^{D} ± 14.2
Fat Weight, kg				
ANC	38.1^{G} ± 7.5	36.6^{H} ± 7.2	32.7^{J} ± 6.9	27.2^{K} ± 6.5
HDC	46.4^{C} ± 12.8	44.4^{D} ± 12.5	39.9^{F} ± 11.4	32.5^{J} ± 11.4
HDC-W	$46.8^{B,C}$ ± 12.54	$5.4^{C,D}$ ± 11.5	$39.4^{F,G}$ ± 12.1	$33.2^{I,J}$ ± 11.2
DXA	50.6^{A} ± 11.9	48.0^{B} ± 11.7	42.6^{E} ± 11.3	34.7^{I} ± 11.2
Fat-Free Weight, kg				
ANC	61.7^{A} ± 8.7	60.2^{B} ± 8.7	58.5^{C} ± 8.7	54.9^{D} ± 8.3
HDC	$53.6^{D,E}$ ± 6.1	$53.3^{E,F}$ ± 6.0	$52.0^{F,G,H}$ ± 6.3	$50.2^{I,J,K}$ ± 5.6
HDC-W	$53.1^{E,G}$ ± 5.9	$51.2^{H,I}$ ± 6.2	$50.6^{H,J}$ ± 6.3	$48.7^{K,M,N}$ ± 5.4
DXA	$49.2^{J,L,M}$ ± 6.74	$8.9^{K,L,O}$ ± 6.3	$47.7^{N,O}$ ± 6.2	47.5^{N} ± 6.1
N_2 Balance, g/d	2.7 ± 1.7	2.6 ± 1.9	2.4 ± 2.1	1.9 ± 2.6

Within a variable, means with different superscripts are statistically different ($p<.05$).

Body weight, analyzed with repeated measures ANOVA to test for a main effect of time, decreased significantly ($p<.0001$). The fat and fat-free weight assessments were analyzed with 2-way repeated measures ANOVAs and the interactions between time and method were significant for fat ($p<.003$) and fat-free weight ($p<.0007$). All assessments of fat weight decreased over time, but the estimates from DXA decreased more than those from ANC. While all methods estimated an overall decrease in fat-free weight, only ANC assessments decreased significantly for each time period. N_2 balance did not change significantly over the time of weight loss ($p=.25$).

The four methods tested in this study yielded different body composition assessments while body weight decreased. The general trends for decreases in both fat weight and fat-free weight are indicated by all four methods, but the amounts indicated by each method differs. Anthropometric assessments indicated significant consistent decreases in both fat and fat-free weights. In contrast, DXA assessed significant consistent decreases only in fat weight.| The lack of a significant consistent decrease in DXA determined fat-free weight is consistent with the absence of a change in N_2 balance. The agreement between DXA and N_2 balance suggest that DXA may be the method of choice for documenting body composition changes during weight loss in women.

1. Lukaski, H.C. (1987) American Journal of Clinical Nutrition, 46, 537-556.
2. Durnin, J.V.G.A. and Wormersley, J. (1974) British Journal of Nutrition, 32, 77-97.
3. Siri, W.E. (1956) Body Composition from Fluid Spaces and Density: Analysis of Methods. Donner Laboratory of Biophysics and Medical Physics. Berkeley, CA.

PROTEOGLYCAN PRODUCTION BY BOVINE RENAL GLOMERULAR MESANGIAL CELLS AND RETINAL MICROVESSEL PERICYTES IN CULTURE

Minto K. Spencer*, Jody A. Rada and Edward C. Carlson
Department of Anatomy and Cell Biology
School of Medicine and Health Sciences, University of North Dakota
Grand Forks, North Dakota 58202

Renal glomerular mesangial cells and pericytes of the retinal microcirculation are closely related and function in maintaining the capillary walls of their respective microvessels. They produce extracellular matrix (ECM) proteins including collagens, laminin, fibronectin, thrombospondin, and several proteoglycans (PG) that contribute to the matrix in the perivascular space. In an effort to determine which PGs may be produced by these cells, we isolated them from fresh bovine kidneys and eyes and established them in tissue culture. Antibodies directed against PGs were used in immunofluorescence studies to compare their secretory potentials.

Adult bovine eyes and kidneys were obtained fresh from a local slaughterhouse. Isolated retinas were homogenized and sieved on a 210 mm nylon screen to prepare microvessels. To generate monolayers of pericytes, vessels were treated with enzymes following which dispersed cells were collected, pelleted, washed with DMEM, then plated on 35mm untreated plastic tissue culture dishes in DMEM supplemented with 20% FBS. Mesangial cell cultures were prepared from 1mm cubes of renal cortex which were passed aseptically over a series of differential metal and nylon mesh screens to isolate glomeruli. These were plated on untreated dishes in RPMI 1640 medium supplemented with 20% FBS. Following two weeks in culture, glomeruli attached to the dishes and cell outgrowths were selectively cultured to obtain colonies of mesangial cells. First through third passage mesangial cells and pericytes were grown on glass slides, fixed, and treated with primary antibodies directed against several PGs, including perlecan, decorin, and biglycan. This was followed by treatment with FITC-conjugated IgG and subsequent examination and photography by fluorescence microscopy.

Second passage mesangial cells were radioactively labeled with $^{35}SO_4$ for 24 hours. Media and cell layers were individually dialyzed to remove the unincorporated radioactive isotope, and lyophilized to concentrate the products. After reconstituting with 6M urea containing 0.15M NaCl, samples were run through DEAE step columns to separate the PGs from the glycoproteins. PGs were eluted by 6M urea containing 1.15M NaCl. Purified PG samples were then dialyzed, lyophilized and separated on a sepharose CL-4B column based on their molecular weights. An aliquot from each fraction was counted for radioactivity, and tubes containing the peak fractions, were pooled, dialyzed, and lyophilized. Aliquots from each peak were digested with heparitinase and chondroitinase ABC. Currently, specific antibodies are being used in Western blot analysis to identify core proteins present in each peak.

Stellate mesangial cell and pericyte monolayers were identified by phase contrast microscopy and by their positive immunofluorescent staining for smooth muscle specific actin (a marker not normally seen in epithelial cell types). By these criteria, mesangial cell and pericyte cultures were >90% homogeneous. Immunofluorescent staining showed the presence of perlecan, decorin, and biglycan while IgG controls were negative. PG fractions obtained from DEAE and Sepharose CL-4B chromatography of mesangial cell layer extracts and the culture media were digested with chondroitinase ABC, electrophoresed on 10% polyacrylamide gels, transferred to nitrocellulose, and reacted with antibodies specific for the core protein of human biglycan in Western blot analyses. Following digestion with chondroitinase ABC, a 55kD band appeared which was not present in the other digested peaks.

Data in the current study indicate that several PGs are produced by pericytes and mesangial cells in culture and these can be identified by immunofluorescence staining and/or Western blot. Early results suggest that in both pericytes and mesangial cells, the production of perlecan > decorin > biglycan. Future studies will center on analysis of the ECM surrounding these cells in vivo to determine whether their potential secretory capacity is expressed in tissues.

BIOCHEMICAL EVALUATION OF COLLAGENS OF BOVINE AND HUMAN RETINAL MICROVESSELS: INCREASED DEPOSITION OF TYPE IV DURING AGING

John C. Swinscoe* and Edward C. Carlson
Department of Anatomy and Cell Biology
School of Medicine and Health Sciences, University of North Dakota
Grand Forks, North Dakota, 58202

The extracellular matrix (ECM) of the retinal microvasculature, which is similar in cow and human, is comprised of several distinct basal laminae, pericytic matrix, and a heterogeneous population of banded collagen fibrils. Numerous morphological studies have shown that this matrix expands with age and in several diseases, most notably diabetes mellitus (1). It is not known, however, which ECM molecules (including specific collagen types) may be altered with age, nor to what extent. Accordingly, the current study was carried out in an effort to demonstrate differences in collagens and their distributions in the aging bovine and human retinal microvascular ECM.

In a recent biochemical study of bovine retinal microvessel ECM isolated by detergent purification, we identified type II collagen as a major constituent using a procedure for separating the extracted collagens into discrete groups (2). In the current study, a modified version of this procedure and immunohistochemical detection techniques were employed to identify resident collagen proteins in the retinal microvessels in calf, cow, and age-pooled human. With these techniques we have been able to demonstrate the comparative distributions of collagen types I-V in the retinal microvascular ECM in calf vs. cow, and cow vs. human, which may be indicative of cell-type specific gene regulation.

In the present investigation, retinal microvascular collagens were quantified following extraction from detergent-purified retinal microvessel ECM and subsequent collagen segregation, based on their physicochemical properties. Following solubilization of the ECM in 0.1mg/ml pepsin, the purified matrix was fractionated by centrifugation and neutral salt solubilization to yield three fractions. Fraction "a" contained type IV collagen, fraction "b" contained types II and V (II, III and V for calf and human), while fraction "c" contained types I-V.

Dry weight analysis indicated that fraction "a" was similar in amount in cow and calf (37%), while fraction "b" was smaller in cow (15%) than in calf (32%). Fraction "c" was larger in cow (52%) than in calf (32%). A different collagen distribution was observed in aging human retinas. Between the ages of 0-40 years, fraction a represented 50%, fraction "b" 4%, and fraction "c" 47 % of pepsin-resistant ECM. Moreover, between the ages of 40-100 years, total collagen content was almost doubled (1.8 fold increase), and was mainly attributed to fraction "c" (2.2 fold increase) rather than fraction "a" (1.3 fold increase), or the minor fraction "b" (3 fold increase). Significantly, between the ages of 40-60 years, fraction "c" increased by 77%.

Data from both bovine and human tissues suggest a possible positive correlation between aging and a shift in the distribution of collagens toward fraction "c". Since more than 65% (by weight) of this fraction is comprised of type IV collagen (the primary collagen in basal laminae), our study indicates that type IV is largely responsible for the increase in ECM collagen deposition in aging retinal microvessels. Our study also shows that type IV collagen alpha chains of bovine fractions "a" and "c", characterized by peptide mapping following conventional cyanogen bromide cleavage and limited enzyme digestion, are not identical and this may signify different type IV collagen isoforms.

1. Carlson, E.C. and N.J. Bjork (1990) Anatomical Record 226:295-306.
2. Swinscoe, J.C. and E.C. Carlson (1995) Microcirculation 2:253-265.

EXPERIMENTAL DNA FINGERPRINTING TECHNIQUES TO ASSESS RELATEDNESS OF GUNNISON'S PRAIRIE DOGS IN COLORADO

Bryan K. Watters*, Donna M. Bruns Stockrahm,
and Chris J. Chastain
Department of Biology, Moorhead State University
Moorhead, MN 56563

The Gunnison's prairie dog, especially the subspecies (Cynomys gunnisoni gunnisoni), has one of the smallest distributions of any prairie dog species, being limited to a very small area in southern Colorado into northern New Mexico. Due to its limited distribution, C. g. gunnisoni could be especially susceptible to inbreeding with the resulting lack of genetic variability.

The study described here is part of a long-term population study on Gunnison's prairie dogs. We ahve live-trapped this populationsince 1991 and believe it to be C. g. gunnisoni. During our 1996 season, we wanted to investigate the amount of relatedness of Gunnison's prairie dogs within a social group, i.e., the breeding group, and between social groups. One main objective was to develop DNA fingerprinting techniques to address the questions of relatedness.

During the summer of 1996, 90 Gunnison's prairie dogs were live-trapped in a 3-ha portion of a larger colony of prairie dogs in Archuleta County, Colorado. Each captured prairie dog was weighed, aged as pup or adult, sexed, ear-tagged, and marked with a unique design on the fur using dye. Reproductive condition and capture location were also recorded before the animal was released. Blood samples were collected from 89 of the prairie dogs by clipping the middle toenail on one of the hind feet. Blood was collected in a 1.5-ml plastic centrifuge tube which contained 0.5 ml of QIAGEN AS1 blood preservative and 6 drops (ca. 0.1 ml) of sodium citrate blood anticoagulant. The protocols used for the isolation of DNA from the blood samples were taken from QIAGEN Inc. (1) and modified for our needs. Our protocols were slightly different due to the use of buffer AS1 blood preservative and incomplete digestion of the proteins after lysis.

Based on groupings of burrow entrances and trapping data, 3 social groups, i.e., breeding groups, appeared to exist in the 3-ha study area. The composition of the captured prairie dogs was: 8 adult females that had been ear-tagged in former years, 3 new adult females, 3 adult males that had been ear-tagged in former years, 7 new adult males, 41 female pups, and 28 male pups.

Preliminary laboratory work indicated that it may be difficult to get consistent results using the RAPD method. To date, we have found that 6 of the microsatellite probes used on northern Idaho ground squirrels (Spermophilus brunneus brunneus) by May et al. (2) are useful for detecting genetic differences in prairie dogs. Future work will consist of testing additional PCR probes, cloning and sequencing all PCR products, and, finally, analyzing banding patterns to determine relatedness and gene flow in our prairie dog population.

1. QIAGEN Inc. (1996) QIAamp Blood Kit and QIAamp Tissue Kit Handbook. Chatsworth, CA. 37pp.
2. May, B., Gavin, T. A, Sherman, P. W., and Korves, T. M. (1997) Molecular Ecology (In press).

OVEREXPRESSION OF FREE RADICAL SCAVENGERS PROTECTS TRANSGENIC PANCREATIC BETA CELLS

B. Xu*, P.M. Kralik and P.N. Epstein
University of North Dakota Dept of Pharmacology and Toxicology, Grand Forks, ND 58202-9037.

Pancreatic beta cells are sensitive to free radicals and this may play an important role in damage to beta cells in type I diabetes and during transplantation. Beta cells contain low levels of enzyme systems that protect against free radicals. The weakest link in their protection system is the deficiency of the two enzymes that detoxify hydrogen peroxide, glutathione peroxide and catalase. We hypothesize that the deficit in the ability to dispose of free radicals is responsible for the unusual sensitivity of beta cells and that increasing protection will result in resistance to diabetes and more effective transplantation. To test these hypotheses we have produced transgenic mice with increased beta cell levels of catalase and we are currently producing mice with elevated metallothionein levels.

Eleven lines of catalase transgenic mice were produced using the insulin promoter to direct pancreatic beta cell specific expression. Catalase activity in these mice was increased by as little as two fold to as much as sixty six fold. Northern blot analysis of several tissues indicated that overexpression was specific to the pancreatic islet. Sixty fold overexpression had no detrimental effects on the islet as demonstrated by normal glucose homeostasis, normal islet morphology and normal glucose stimulated insulin secretion. To test whether increased catalase activity could protect the transgenic islet we have exposed islets to hydrogen peroxide and alloxan. Toxicity was evaluated by measuring the decrease in insulin secretion. Sixty fold overexpression of catalase produced almost complete protection of islets against 1 mM hydrogen peroxide and about 70 percent protection against 2 mM hydrogen peroxide. Lower levels of catalase expression in a different transgenic line produced significant but lesser protection (not shown). Catalase also provided partial protection against alloxan toxicity. At 1 mM alloxan overexpression of catalase by fifty fold reduced alloxan toxicity by 24 percent ($p<0.05$). Comparison of the alloxan and hydrogen peroxide results suggests that alloxan toxicity is due to compounds in addition to hydrogen peroxide. These transgenic mice provide a valuable model for evaluating the role of free radicals in beta cell pathology and diabetes.

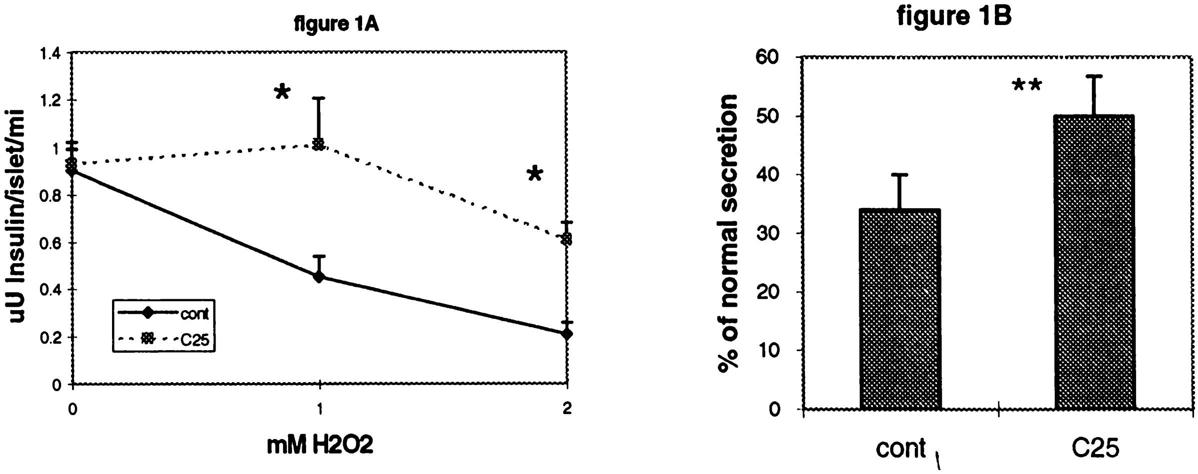


*Fig.1. Sixty six fold overexpression of catalase protects transgenic islets from 1 or 2 mM hydrogen peroxide (figure 1A) and 1 mM alloxan. (figure 1B). Values are the means obtained from at least five assays. * or ** indicates different from the control value p<0.01 or p<0.05, repectively by one tailed students t-test. Vertical bars are the standard error.*

CONSTITUTION OF THE NORTH DAKOTA ACADEMY OF SCIENCE

(Founded 1908, Official State Academy 1958)

ARTICLE I - NAME AND PURPOSE

1. This association shall be called the NORTH DAKOTA ACADEMY of SCIENCE (NDAS).

2. The purpose of this association shall be to promote and conduct scientific research and to diffuse scientific knowledge.

ARTICLE II - MEMBERSHIP

1. Membership in the NDAS shall be composed of persons active or interested in some field of scientific endeavor. Candidates for membership may be proposed by any active member of the NDAS by submitting the candidate's name to the chairman of the Membership Committee for approval. Specific categories of membership shall be defined in the bylaws of the NDAS.

2. Annual dues for the various categories of membership shall be determined by the members present at the Annual Meeting.

ARTICLE III - OFFICERS

1. The Officers of the NDAS shall be a President, President-Elect, and the Secretary-Treasurer who shall perform the duties usually pertaining to these offices. The President-Elect shall be chosen by ballot at the Annual Meeting and will hold the office for one year and then assume the office of President for one year. The Secretary-Treasurer shall be appointed for a three-year term by the Executive Committee.

2. The Executive Committee, consisting of the above-named officers, the retiring President, and three members-at-large, shall have charge of the ordinary executive duties. The members-at-large shall be elected for a three-year term on a rotating basis.

ARTICLE IV - MEETINGS

1. There shall be an Annual Meeting each year held at such time and place as the Executive Committee may determine.

2. Special meetings shall be called by the President upon the request of ten percent of the active members. Only matters specified in the call can be transacted at a special meeting.

3. Ten percent of the active members shall constitute a quorum at the Annual Meeting. Special meetings require twenty percent of the active members for a quorum.

ARTICLE V - MISCELLANEOUS

1. In the event of dissolution of the NDAS, any remaining assets shall be distributed to organizations organized and operated exclusively for educational and scientific purposes as shall at the time qualify as exempt organizations under Section 501(c)(3) of the Internal Revenue Code of 1954.

2. No substantial part of the activities of the NDAS shall be the carrying on of propaganda, or otherwise attempting to influence legislation, and the Academy shall not participate in or intervene in, any political campaign on behalf of any candidate for public office.

3. No part of any net earnings shall inure to the benefit of, or be distributable to, NDAS members or officers, or other private persons, except that the academy may authorize the payment of reasonable compensation for services rendered.

ARTICLE VI - AMENDMENTS

1. This Constitution may be amended at any Annual Meeting of the NDAS by a two-thirds vote. Proposed amendments shall be submitted in writing to the Secretary who shall send them to the members at least two weeks before the meeting at which such amendments are to be considered.

2. Bylaws may be adopted or repealed at any regular meeting by a two-thirds vote.

BY-LAWS OF THE NORTH DAKOTA ACADEMY OF SCIENCE

1. The NDAS official guide for parliamentary procedure shall be the "Standard Code of Parliamentary Procedure" by Alice F. Sturgis. (1965 Revision)
2. The annual dues shall be determined by a two-thirds vote at an Annual Meeting. These dues are payable 1 January of each year. (1965 Revision)
3. Members shall be dropped from the active list on 31 December following the nonpayment of dues during the membership year commencing the previous 1 January. A member may return to the active list by paying the current year dues and a membership renewal charge of $5.00. (1975 Revision)
4. Every member in good standing shall receive a copy of the annual Proceedings of the North Dakota Academy of Science. (1965 Revision)
5. Special offices such as Historian may be created by the unanimous vote of the members at the Annual Meeting. (1965 Revision)
6. The Executive Committee shall annually appoint an Academy representative to the National Association of Academies of Science and to Section X (General) of the American Association for the Advancement of Science. (1979 Revision)
7. The Committee structure of the NDAS shall be as follows, the ***President*** appointing the members and chairpersons for all except the Executive Committee:
   a. **Executive Committee.**
   Membership: Past-President, President, President-Elect, Secretary-Treasurer, three members-at-large. {Three-year terms}
   Duties: The Executive Committee shall be the governing board of the NDAS, responsible only to the membership. It shall arrange for programs, approve committee appointments, be responsible for the fiscal affairs of the Academy, and transact such business as necessary and desirable for function and growth of the NDAS.
   b. **Editorial Committee.**
   Membership: Three members. {Three-year terms}
   Duties: The Editorial Committee shall develop and recommend the NDAS publication program and policies to the Executive Committee. It will assist the Editor in reviewing manuscripts for the Proceedings.
   c. **Education Committee.**
   Membership: Seven members, two shall be high school teachers. {Five-year terms.}
   Duties: The Education Committee shall work with high school students and teachers in the state, in visitation programs, Science Talent Search programs, and other programs to stimulate an interest in science by the youth of the state. It shall operate the Junior Academy of Science program and administer the AAAS high school research program.
   d. **Denison Awards Committee.**
   Membership: Six members. {Three-year terms}
   Duties: The Denison Awards Committee shall have as its prime duty the judging of student research and paper competitions, both undergraduate and graduate, and any other similar competitions. The committee shall also maintain the criteria to be used in the judging and selection of papers, such criteria to be circulated to prospective competitors. (1985 Revision)
   e. **Necrology Committee.**
   Membership: Three members. {Three-year terms}
   Duties: The Necrology Committee shall report to the annual meeting on those departed during the preceding year. Obituaries may be included in the minutes of the annual meeting and/or published in the Proceedings.
   f. **Nominating Committee.**
   Membership: The five most recent past-presidents.
   Duties: The Nominating Committee shall propose a slate of at least two nominees for each of the offices as needed. The committee report shall be submitted to the President prior to the annual meeting as well as reported to the membership at the appropriate time for action.
   g. **Resolution Committee.**
   Membership: Three members. {Three-year terms}

Duties: The Committee on Resolutions shall prepare such resolutions of recognition and thanks as appropriate for the annual meeting. Further, the Committee shall receive suggested resolutions for the membership and transmit such resolutions and the Committee recommendation to the membership.

h. **Membership Committee.**
Membership: Unlimited number. {Appointed annually}
Duties: The Membership Committee shall promote membership in the NDAS. It shall conduct an annual canvass of the Institutions of Higher Education, Government Agencies, and other related organizations for the purpose of providing opportunity for prospective members to join the NDAS. Further, this Committee shall make recommendations to the Executive Committee of potential candidates for emeritus and honorary memberships.

8. The *Nominating Committee* shall be responsible for all nominations to elective office and shall be required to advance at least two names for each open position. Academy members shall have been encouraged to suggest nominees to the committee prior to the Committee submitting its report. A ballot, incorporating brief biographical information, shall be distributed by the Secretary-Treasurer to all members prior to the Annual Meeting. Those ballots may be returned by mail, or in person at the Annual Meeting, until the announced deadlines. The results of the election shall be announced at the Annual Meeting.

9. *Categories of Membership*:

a. *Active members* - shall be persons interested or actively participating in some scientific endeavor. Active members may participate in all activities of the NDAS.

b. *Student members* - shall be graduate or undergraduate College students in some field of science. Student members may participate in all activities of the NDAS, with the exception of holding office.

c. *Sustaining members* - are persons or organizations interested in the activities of the NDAS. Sustaining members may participate in all activities of the NDAS, with the exception of voting or holding office. Sustaining members may be of three types: Individual, Corporate, or Institutional. (1965 Revision)

This bylaw subsection is implemented by the following action of the Executive Committee (10-25-85):

There shall be two categories of Sustaining Membership, *Patron* members and *Sponsor* members. The annual membership fee shall be $100 for *Patron* members and $50 for *Sponsoring* members. Benefits accruing to Corporate Sustaining Members include:

1. Positive public relations through support of science and technology in North Dakota.
2. Preference in mounting commercial displays at the annual meetings of the NDAS.
3. Early access to research results and early awareness of research programs through first hand association with scientists and engineers.
4. Improved commercial opportunities through association with members, institutions, and other sustaining members.
5. Improved future commercial opportunities through exposure to students contemplating careers in science or technology.

Until action is taken otherwise, the Corporate Sustaining Membership fees shall be placed in the North Dakota Science Research Foundation for the support of scientific research.

d. *Emeritus Membership.* Any member in good standing upon formal retirement is eligible for emeritus membership. Nominations may be forwarded to the Membership Committee by any member, and it shall be the responsibility of the membership committee to review the membership list for possible candidates. The Executive Committee shall approve nominations. Emeritus members shall retain all rights of active members but will be exempt from payment of dues. (1973 Revision)

e. *Honorary Membership.* The Academy may recognize, by awarding honorary membership, any person (nonmember or member) who has in any way made an outstanding contribution to science. It shall be the responsibility of the Membership Committee to be aware of individuals whom it would be fitting for the NDAS to honor in this fashion. Any member may submit nominations along with supporting data to the Membership Committee. Approval of nominations shall be by a two-thirds majority of those attending the annual meeting. (1973 Revision)

10. The President, with the approval of the Executive Committee, shall appoint members to serve on *ad hoc* committees. Reports of *ad hoc* committees shall be presented to the Executive Committee or to the annual meeting. Ad hoc committees serve only during the tenure of the president who appointed them. (1965 Revision)

11. The Executive Committee shall appoint an Editor who shall edit the PROCEEDINGS. The Editor shall be appointed for a three-year term. The salary of the Editor shall be set by the Executive Committee. (1975 Revision)
12. The annual dues shall be $15.00 per year for professional members, with $2.00 designated for the North Dakota Science Research Foundation, and $5.00 per year for student members. (1994 Revision)
13. The Executive Committee is empowered to charge a publication fee of authors of up to $10.00 per page. (1965 Revision)
14. All student research participants shall receive a properly inscribed certificate and be invited to the banquet dinner as the guests of the NDAS. (1965 Revision)
15. All activities of the Academy, including grant applications, are to be handled through the Academy Offices from now on. (1966 Revision)
16. The Executive Committee of the NDAS is instructed to establish a J Donald Henderson Memorial Fund and to administer this fund so that the proceeds will be used to promote science in North Dakota. (1967 Revision)
17. The fiscal year of the North Dakota Academy of Science, for the purpose of financial business, shall be 1 January to 31 December. (1973 Revision)
18. The NDAS establishes the North Dakota Academy of Science Achievement Award to be given periodically to a NDAS member in recognition of excellence in one or more of the following:
    a. Nationally recognized scientific research.
    b. Science education.
    c. Service to the NDAS in advancing its goals.

    The Nominating Committee will administer the selection process, will develop a separate funding source for a monetary award, and will develop, for Executive Committee approval, the criteria for the award. (1988 Revision)
19. The **North Dakota Science Research Foundation** is established as an operating arm of the NDAS. The purposes of the Foundation are:

    (1) to receive funds from grants, gifts, bequests, and contributions from organizations and individuals, and
    (2) to use the income solely for the making of grants in support of scientific research in the State of North Dakota. Not less than 50% of the eligible monies received shall be placed in an endowment from which only the accrued interest shall be granted.

    The foundation shall be responsible for soliciting the funds for the purposes described. The Foundation funds shall be in the custody of the Secretary-Treasurer of the NDAS and shall be separately accounted for annually.

    The *Foundation Board of Directors* shall be comprised of five members of the NDAS, representing different disciplines. Members shall be appointed by the President for staggered five year terms. The chairperson of the Board shall be appointed annually by the President. The Board shall be responsible for developing operating procedures, guidelines for proposals, evaluation criteria, granting policies, monitoring procedures, and reporting requirements, all of which shall be submitted to the Executive Committee for ratification before implementation.

    The Foundation shall present a written and oral report to the membership of the NDAS at each annual meeting, and the Secretary-Treasurer shall present an accompanying financial report. (1989 Revision)

By-Laws last revised, May, 1994.

MINUTES (UNAPPROVED) OF THE ANNUAL BUSINESS MEETING
April 26, 1997
Valley City State University

1. The Annual Luncheon of the NDAS began at 12:00 in the Student Senate Room of the Student Memorial Center, Valley City State University. About 85 were in attendance including participants, parents, and teachers associated with the Junior Academy of Science and the Denison Research paper competitions, members and guests.

2. Winners of the A Roger Denison Research Competition were announced at the Annual Banquet, Thursday evening.
Undergraduate — 5 papers
Shelly L Satran First place
certificate of participation and $100
Gregory Nelson Runner Up
certificate of participation and $ 50
Heather Plum Runner Up
certificate of participation and $ 50
Graduate — 15 papers.
Jolin A Jegier Runner up First place
certificate of participation and $100
Anne C Deitz Runner up First place
certificate of participation and $100

3. Thanks to the very efficient functioning of all judges for the student research paper competitions of the Junior Academy of Science, Secretary-Treasurer Garvey was able to announce the winners and present awards as follows:
Junior Division — 10 Papers
Cortland Barnes First Place
certificate and check for $100
Brittany Payeur Second Place
certificate and check for $ 50
Jeremy Pankow Third Place
certificate and check for $ 25
Kristen Kingsbury Third Place
certificate and check for $ 25
Senior Division — 8 papers
Peter Haugen First Place
certificate and check for $100
plus $150 paid toward tuition if attending ND
Institution of Higher Education.
Kelly Kingsbury Second Place
certificate and check for $ 50
Erin Nyren Third Place
certificate and check for $ 25
The names of the above students will be submitted to the Minnesota Academy of Science as presenters to attend the Minnesota Academy Junior Science and Humanities Symposium, October, 1996.

Amy Braaten was selected to receive the $100 savings bond for the best Chemistry related project given by the Red River Valley Section of the American Chemical Society.

4. The luncheon continued until 12:40. Those in attendance wish to express our thanks, with compliments, to the Foods Service of Valley City State University for the excellence of the meal and refreshments throughout the two days of our meeting.

5. 22 Members and guests moved to the Presidents/Norway Room of the Student Memorial Center where President Eileen Starr convened the Annual Business Meeting at 1:00 pm. Note shall be made that Jim Walla, member of the ND

Science Research Foundation Board of Directors should be identified with North Dakota State University. Please make the corresponding adjustment to page 189 of your copy of the Proceedings.

6. Some meeting statistics:
124 registered at the NDAS arena.
76 Students of VCSU attended session
25 Professional communications.
3 Symposia with 26 presentations.
9 panel members round the table discussing Economic Development.
69 attended the Annual Banquet.

7. President Starr opened with remarks describing the success of the Annual meeting. The attendance surpassed that to the meeting last year in Bismarck and was about three times that of the meeting in Fargo two years ago.

8. Treasurer Garvey reported on the cash flow problems of the Academy. The financial statement presented in the Proceedings showed that the Academy began the fiscal year with a checking balance of $23.89 and a net change of $-1906.85 for the 1995 fiscal year. To cover pre-meeting expenses, Garvey transferred $2200 from the ND Science Research Foundation savings account as a loan at 7% to the Academy checking account. At the close of the meeting (accounting done Friday night against deposits made Friday afternoon) with no meeting expenses bills in hand, the checking balance was $636.41 (with $2457.51 belonging to the ND Science Research Foundation, and $285.52 belonging to the Scholarship fund) leaving the Academy owing its operating subsidiaries $2106.62. With meeting expenses yet to be received, we can only hope that the Academy checking account can be balanced by the end of December.

9. Secretary-Treasurer Garvey presented the results of the election. 25 Ballots were submitted.
Dan Mott, President Elect,
Dickinson State University
James Anderson, Member at Large
North Dakota State University

The newly elected members of the Executive Committee join with President Hunt, Past President Starr, Secretary-Treasurer Eric Uthus and Member at Large Allen Kihm. It would be appropriate to elect an additional member at large to replace Dan Mott. The Executive Committee will deal with the situation at its first meeting.

10. Interest from a Treasury Bill, interest from loans made to the Academy cash flow , and generous contributions from the members make it possible to again award a grant from the North Dakota Science Research Foundation. This year the Board of Directors received three applications. The proposal submitted by David B Rush (M S Student in the Department of Geology and Geological Engineering, University of North Dakota) entitled *Characterization of the Hyporheic Zone of a Northern Prairie Stream Catchment* was granted the amount of $500. Secretary-Treasurer Garvey will prepare the necessary documents to activate the grant.

On 29 March, 1996, Secretary-Treasurer Garvey received a letter from Karyn A Alme, Recipient of a ND Science Research Foundation grant in 1995. In part the letter reads I attempted to carry out the field research required for this project. I traveled to areas in and around Mott, Hettinger, and Hazelton, North Dakota, hoping to identify research sites based on previously identified sited depicted in air photos. Unfortunately, wet weather in the past several years has caused such rapid vegetation growth that these features have been obscured. As a result, I was unable to locate any polygonal features. I have, therefore, had to change my thesis project to one involving till stratigraphy in eastern North Dakota. I enclose my expense report for travel costs incurred, and inform you that I am releasing the remainder of the grant back to the North Dakota Science Research Foundation (total expenses = $271.50). To date, the University of North Dakota has not made the reimbursement payment from UND fund # 5144 nor has the Board of Directors of the Science Research Foundation communicated any alternate disposition.

11. President Starr asked that we devote a moment of silence in memory of those of our membership who have passed on (Proceedings, page 199)

12. President Starr introduced President Elect Hunt. The gavel was transferred and President Hunt continued the

meeting. As a first order of business, President Hunt presented Past President Starr with a certificate in appreciation of her selfless service to the Academy during the past year.

13. President Hunt continued the meeting by noting some additional changes for the coming year.

Roy Garvey declined reappointment as Secretary-Treasurer. The Executive Committee has recruited Eric Uthus, Human Nutrition Research Center, Grand Forks, to fill the position. Editorship of the Proceedings will also pass into the capable hands of Dr Uthus. It is proposed that the transfer of files shall occur on 8 May, 1996. At that time, the Office of the Academy will again be situated in Grand Forks.

14. While reviewing some ideas on the future direction of the Academy, President Hunt reiterated the view that the Academy remain a representation of the science done in North Dakota. The change in format of the Proceedings to that of two columns and mechanism of transmitting communications to the Editor is a step in an evolution to a document which may better suit the needs of the contributors and readers alike. The expansion of symposium papers to a multiple page format should give the authors a chance to better present the state of the science and will hopefully make the contribution more acceptable for use in support of tenure and promotion evaluations. The new editor will expect to receive all communications and symposium papers on magnetic media, which will facilitate format alteration as required. A set of guidelines will be evolved in consultation with members of the editorial committee which specify page margins, font and point sizes. All contributions will be supported by an ASCII text abstract submitted on diskette or via e-mail. This abstract will be used in generation of a CD-ROM with abstracts of all papers presented in Proceedings of all of the Academies of Science. The longer papers will be assessed a $10 per page charge to offset printing costs.

15. President Hunt envisions the North Dakota Academy of Science becoming a Federation of Science Organizations with Chapters in North Dakota . The Annual Meeting might become an umbrella where several organizations can congregate at a common site over an overlapping time period with the programs of each group intertwined as appropriate. A common Banquet might meet the needs of several organizations. The resources of each individual organization can be expanded, but we would not expect any loss of identity.

16. President Hunt introduced James Penland as the new chairman of the Membership Committee. Closer concentration on individual campuses will be the goal. The committee will come up with new recruiting materials describing the Academy and Why I should be a member. E-mail addresses will be requested. It may be possible to lower the postage costs if a significant number of the membership can be reached via e-mail. Notice of meetings, dues requests, and other forms of communication may be significantly improved.

17. President Hunt proposes that the date that dues become delinquent be shifted from the 1 January date currently used by Garvey. This falls in the Holiday season and may contribute to the number of drops which occur each year. Also, it is suggested that the Academy have activities during other times of the year. A single Annual meeting is a good time to get together, but activities at other times of the year may help involve more members in the workings of the organization. It is suggested that, for example, the Academy presence increase at the Science and Engineering Fairs, at the Science Olympiad, that the *Visiting Scientist* program be revitalized. Most of our institutions recognize such participation as recruiting and/or public relations activities.

18. The clock again forced the meeting to an end. Afternoon sessions were beginning. Meeting adjourned at 1:32 pm.

Roy Garvey
Secretary-Treasurer

ACADEMY OFFICERS AND COMMITTEES

Executive Committee
Membership:
Past-President
President
President-Elect
Secretary-Treasurer
Three Members-at-Large (three-year terms)

President
Curtiss Hunt
1996-1997
USDA, ARS Human Nurtition
Research CenterPO Box 9034
Grand Forks, ND 58202
(701) 795-8423
chunt@badlands.nodak.edu

Past-President
Eileen Starr
1996-1997
Division of Sciences
Valley City State University
Valley City, ND 58072
(701) 845-7522
eileen_starr@mail.vcsu.nodak.edu

President-Elect
Dan Mott
1996-1997
Department of Natural Science
Dickinson State University
Dickinson, ND 58601-4896
(701) 227-2111
daniel_mott@dsu1.dsu.nodak.edu

Secretary-Treasurer
Eric Uthus
1996-
USDA, ARS Human Nurtition
Research Center
PO Box 9034
Grand Forks, ND 58202
(701) 795-8382
uthus@badlands.nodak.edu

Member-at-Large
Allen Kihm
1995-1998
Division of Science
Minot State University
Minot, ND 58707-5002
(701) 845-7452
kihm@warp6.cs.misu.nodak.edu

Member-at-Large
Eric Hugo
1996-1999
Department of Natural Sciences
Dickinson State University
Dickinson, ND 58601-4896
(701) 227-2069
e_hugo@dsu1.dsu.nodak.edu

Member-at-Large
Rich Novy
1996-1999
Department of Plant Science
North Dakota State University
Fargo, ND 58105
novy@prairie.nodak.edu

Editorial Committee

Membership:
Three Members (three-year terms)

Allen Kihm
1995-1998
Minot State University

Mark Hoffmann
1997-2000
University of North Dakota

Education Committee

Membership:
Seven members, two shall be high school teachers (five-year terms)

Junior Academy of Science
Dana Metzger
University of North Dakota

Junior Academy of Science
Melanie Kathrein
Dickinson State University

Denison Awards Committee

Membership:
Six members (three-year terms)

Dan Mott
Dickinson State University
Denison Graduate

John Webster
1997-2000
(Denison Undergraduate)

Margaret Lowe
1997-2000
(Denison Graduate)

Bruce Jensen
Jamestown College

Diane Larson
1997-2000
Northern Prairie Widlife Res Ctr

Eric Hugo
Dickinson State University

Necrology Committee

Membership:
Three members (three-year terms)

Mike Thompson
-1997
Minot State University

Nominating Committee

Membership:
The five most recent past-presidents (five-year terms)

Clark Markell
1991-1992
Minot State University

John Brauner
1993-1994
Jamestown College

Glen Statler
1994-1995
North Dakota State University

David Davis
1990-1991
Bioscience Research Lab, Fargo

Eileen Starr
1996-1997
Valley City State University

Resoultion Committee

Membership:
Three members (three-year terms)

David Hein
University of North Dakota

Membership Committee

Membership:
unlimited number (appointed annually)

Mike Thompson
Minot State University

Joseph Stickler
Valley City State University

Dorothy Johansen
Mayville State University

Dan Mott
Dickinson State University

Gary Clambey
North Dakota State University

Frank Koch
Bismarck State College

James Penland
USDA, Grand Forks

Vernon Feil
USDA Bioscience, Fargo

David Berryhill
North Dakota State University

North Dakota Research Foundation Board of Directors

Membership:

Lisa Nolan
North Dakota State University

Ken Ruit
University of North Dakota

Jim Walla
-1997
North Dakota State University

Ken Pierce
Dickinson

PAST PRESIDENTS AND LOCATION OF THE ANNUAL MEETING

NORTH DAKOTA ACADEMY of SCIENCE

1909	M A Brannon	Grand Forks
1910	M A Brannon	Fargo
1911	C B Waldron	Grand Forks
1912	L B McMullen	Fargo
1913	Louis VanEs	Grand Forks
1914	A G Leonard	Fargo
1915	W B Bell	Grand Forks
1916	Lura Perrine	Fargo
1917	A H Taylor	Grand Forks
1918	R C Doneghue	Fargo
1919	H E French	Grand Forks
1920	J W Ince	Fargo
1921	L R Waldron	Grand Forks
1922	Daniel Freeman	Fargo
1923	Norma Preifer	Grand Forks
1924	O A Stevens	Fargo
1925	David R Jenkins	Grand Forks
1926	E S Reynolds	Fargo
1927	Karl H Fussler	Grand Forks
1928	H L Walster	Fargo
1929	G A Talbert	Grand Forks
1930	R M Dolve	Fargo
1931	H E Simpson	Grand Forks
1932	A D Wheedon	Fargo
1933	G C Wheeler	Grand Forks
1934	C I Nelson	Fargo
1935	E A Baird	Grand Forks
1936	L R Waldron	Fargo
1937	J L Hundley	Grand Forks
1938	P J Olson	Fargo
1939	E D Coon	Grand Forks
1940	J R Dice	Fargo
1941	F C Foley	Grand Forks
1942	F W Christensen	Fargo
1943	Neal Weber	Grand Forks
1944	E A Helgeson	Fargo
1945	W H Moran	Grand Forks
1946	J A Longwell	Fargo
1947	A M Cooley	Grand Forks
1948	R H Harris	Fargo
1949	R B Witmer	Grand Forks
1950	R E Dunbar	Fargo
1951	A K Saiki	Grand Forks
1952	Glenn Smith	Fargo
1953	Wilson Laird	Grand Forks
1954	C O Clagett	Fargo
1955	G A Abbott	Grand Forks
1956	H B Hart	Jamestown
1957	W E Cornatzer	Grand Forks
1958	W C Whitman	Fargo
1959	Arthur W Koth	Minot
1960	H J Klosterman	Fargo
1961	Vera Facey	Grand Forks
1962	J F Cassel	Fargo
1963	C A Wardner	Grand Forks
1964	Fred H Sands	Fargo
1965	P B Kannowski	Grand Forks
1966	Paul C Sandal	Fargo
1967	F D Holland, Jr	Grand Forks
1968	W E Dinusson	Fargo
1969	Paul D Leiby	Minot
1970	Roland G Severson	Grand Forks
1971	Robert L Burgess	Fargo
1972	John C Thompson	Dickinson
1973	John R Reid	Grand Forks
1974	Richard L Kiesling	Fargo
1975	Arthur W DaFoe	Valley City
1976	Donald R Scoby	Fargo
1977	Om P Madhok	Minot
1978	James A Stewart	Grand Forks
1979	Jerome M Knoblich	Aberdeen, SD
1980	Duane O Erickson	Fargo
1981	Robert G Todd	Dickinson
1982	Eric N Clausen	Bismark
1983	Virgil I Stenberg	Grand Forks
1984	Gary Clambey	Fargo
1985	Michael Thompson	Minot
1986	Elliot Shubert	Grand Forks
1987	William Barker	Fargo
1988	Bonnie Heidel	Bismark
1989	Forrest Nielsen	Grand Forks
1990	David Davis	Fargo
1991	Clark Markell	Minot
1992	John Brauner(elect)	Grand Forks
1993	John Brauner	Jamestown
1994	Glen Statler	Fargo
1995	Carolyn Godfread	Bismarck
1996	Eileen Starr	Valley City
1997	Curtiss Hunt	Grand Forks

Fiscal Year	1995	1996
ASSETS		
Operating Accounts		
Checking	23.89	-424.21
Trust Accounts		
Scholarship	23206.92	23700.57
Research Foundation	12060.19	13372.85
Total	35291.00	36649.21
LIABILITIES		
Advanced Dues Payments	78.00	
Restricted Purpose Funds		
Scholarship Principal	23206.92	23700.57
Research Foundation	12060.19	13372.85
Total	35345.11	37073.42
Accumulated Surplus	-54.11	-424.21
Change in Surplus		-370.10
OPERATING CASH FLOW		
Cash on Hand, 1 January	1930.74	23.38
Receipts for Year	6578.95	8040.10
Resources Available	8509.69	8063.48
Disbursements	8485.80	8487.69
Cash Balance 31 December	23.89	-424.21
Increase over Year	-1906.85	-447.59
DUES		
Reinstatements		
Current year	1673.00	
Future Years	78.00	
Sponsor/Patron	599.00	
Total	2350.00	1069.50
INSTITUTIONAL SUPPORT		
UND		1000.00
Valley City StateUniversity		250.00
NDAS Research Foundation	1200.00	
Total	1200.00	1250.00
ANNUAL MEETING		
Registration Fees	1005.00	4148.00
Banquet	526.00	
Luncheon		
Sigma Xi - Minot	50.00	
Sigma Xi - UND	50.00	
Total	1631.00	4148.00
AWARDS PROGRAM		
Scholarship Dividends	829.45	832.20
ND Research Foundation	456.00	500.00
Total	1285.45	1332.20
PUBLICATION SALES	112.50	
MISCELLANEOUS INCOME		240.40
TOTAL INCOME	**6578.95**	**8040.10**

MEMBERSHIP		
Emeritus	52	58
Students	41	53
Professional	161	178
Deliquent	140	83*
Dropped	88	3
Other	19	
Total	501	375
Member Count	413	289

*1995 or before

ANNUAL MEETING		
Speakers Expenses		
Meals/Refreshments	2504.71	1915.55
Printing		
General Expenses		
Total	2504.71	1915.55
AWARD PROGRAMS		
ND Science/Engineering Fair	50.00	50.00
Denison	400.00	400.00
ND Jr Academy	350.00	397.50
Research Foundation Grant	500.00	500.00
Total	1300.00	1347.50
PUBLICATION		
Proceedings	2507.00	3699.00
Total	2507.00	3699.00
OFFICE EXPENSES		
Postage	268.74	652.38
Post Office Box Rental	58.00	
Duplication	283.21	84.60
Supplies	63.66	
Phone	2.96	
Other		501.46
Total	676.57	1238.44
MISCELLANEOUS		
Fidelity Bond	26.00	26.00
NAAS Dues	70.00	70.00
Other	1403.00	23.20
RF Loan Interest		168.00
Total	1499.00	287.20
TOTAL DISBURSEMENTS	**8487.28**	**8487.69**

SCIENCE RESEARCH FOUNDATION	1995	1996
CASH INCOME		
Donations from Members	212.00	110.00
Allocations from Dues	244.00	298.00
Interest Accrued	425.08	1012.50
Sponsors/Patrons		
Total	**881.08**	**1420.50**
CASH EXPENSE		
Grants	500.00	500.00
Interest Compounding	425.08	1012.50
Other Disbursements	18.00	
Total	**943.08**	**1512.50**
Net Change	-62.00	-92.00
ASSETS		
Pass Book Savings, 31 Dec	2060.19	3372.85
T-Note, book value	10000.00	10000.00
Inverstment Total	**12060.19**	**13372.85**
Change		1312.66

SCHOLARSHIP FUND	1995	1996
CASH INCOME		
ENOVA (SDGE)	426.25	429.00
IES Industries	403.20	403.20
Total	**829.45**	**832.20**
CASH EXPENSE		
Denison Awards	400.00	400.00
Junior Academy Awards	400.00	375.00
ND Science and Engineering Fair	50.00	50.00
Other Expenses		22.50
Total	**850.00**	**825.00**
Net Change	-20.55	7.20
ASSETS		
ENOVA Shares (1983, 250 shares)	758.86	792.83
Price 18.50	23.75	22.66
Value 4625.00	18022.92	17965.53
IES Industries (1990, 120 shares)	192.00	192.00
Price 31.63	27.00	29.87
Value 3795.60	5184.00	5735.04
Total Investment Value	**23206.92**	**23700.57**
Change		493.64

The 1996 statement of financial status has not been reviewed by the Audit Committee

Richard M. Marwin

Dr. Richard M. Marwin was 77 at the time of his death. He was born December 10, 1918 in Minneapolis, Minnesota. He earned his B.S., M.S. and Ph.D. degrees from the University of Minnesosta. He served in the U.S. Army Sanitary Corp during WWII. In September 1948, Dr. Marwin joined the staff of the UND Medical School and became a member of the Academy in 1949. He served UND for 35 years before retiring in July of 1983. He died October 2, 1996.

\

ABRAHAMSON, Harmon B	University of North Dakota	Grand Forks	ND	58202	701 777 2741	P
ADOLF, Stacy L	Moorhead State University	Moorhead	MN	56563	218 236 3347	S
ALESSI, Joseph	705 Franklin Street North	Glenwood	MN	56334		E
ALEXANDER, Bonnie J	Valley City State University	Valley City	ND	58072		P
ALLARD, Jennifer L.	624 18th St NW Apt B	Minot	ND	58701		S
ALTENBURG, Karl R	709 Nineth Avenue North	Fargo	ND	58102		P
ALVAREZ, Enrique	P O Box 324	Bismarck	ND	58502		S
ANDERSON, Edwin M	1151 Twelveth Avenue West	Dickinson	ND	58601		E
ANDERSON, Ordean S	Rural Route 1, Box 269	New Prague	MN	56071	507 364 8744	P
AUYONG, Theodore	3614 Eleventh Avenue North	Grand Forks	ND	58201	701 772 3166	E
BALACHANDRAN, Chandra S	North Dakota State University	Fargo	ND	58105	701 231 7115	P
BARNEY, William G	1525 Cottonwood	Grand Forks	ND	58201		E
BARNHART, Michael P	2704 Tenth Avenue NW	Mandan	ND	58554	701 663 4980	P
BEHM, Marla	516 North 19th Street	Bismarck	ND	58501	701 258 7451	P
BELINSKEY, Carol R	900 Fourth Avenue NW	Minot	ND	58703		E
BERG, Candace R	RR1 Box 41	York	ND	58386		S
BERKEY, Gordon B	Minot State University	Minot	ND	58707		P
BERRYHILL, David L	North Dakota State University	Fargo	ND	58105	701 231 7694	P
BICKEL, David	ND Public Service Commission	Bismarck	ND	58505	701 328 2249	P
BIEK, Robert F	North Dakota Geological Survey	Bismarck	ND	58505	701 224 4109	P
BLACK CLOUD, Randy	University of North Dakota	Grand Forks	ND	58202		S
BLAKE, Michael J	UND School of Medicine	Grand Forks	ND	58202	701 777 4293	P
BLUEMLE, John P	North Dakota Geological Survey	Bismarck	ND	58505	701 328 9700	P
BRAUNER, Carolyn R	Valley City State University	Valley City	ND	58072	701 795 1924	P
BRAUNER, John F	Jamestown College	Jamestown	ND	58405		P
BREKKE, David W	University of North Dakota	Grand Forks	ND	58202	701 777 5154	P
BRISKE-ANDERSON, Mary	Human Nutrition Research Center	Grand Forks	ND	58202	701 795 8402	P
BROPHY, John A	702 South Drive	Fargo	ND	58103	701 235 2772	E
BROWN, Ralph C	Box 89	Stoneham	ME	43310		E
CALLENBACH, John A	North Dakota State University	Fargo	ND	58105	701 231 7582	E
CAMPBELL, Earle H	N D Paleontological Society	Bismarck	ND	58502	701 255 3658	P
CAMPBELL, Johnathan M	408 North Second Street	Bismarck	ND	58501		P
CARLSON, Kenneth T	515 East Thirteenth Street	Casper	WY	82601		E
CARLSON, Ed	University of North Dakota	Grand Forks	ND	58202		P
CARMICHAEL, Virgil W	1013 North Anderson Street	Bismarck	ND	58501	701 223 7986	E
CARTER, Jack F	1345 Eleventh Street North	Fargo	ND	58102	701 232 0482	E
CASSEL, J Frank	83 West Boulder Street	Colorado Springs	CO	80903		E
CHAMBERS, Michael A	North Dakota State Universit	Fargo	ND	58105		S
CLAMBEY, Gary K	North Dakota State University	Fargo	ND	58105	701 231 8404	P
CLAUSEN, Eric N	Minot State University	Minot	ND	58707		P
CONNETT, Peter	Saint Lawrence University	Canton	NY	13617		S
CORNATZER, William E	2033 North Washington Street	Bismarck	ND	58501		E
CRAWFORD, Richard	University of North Dakota	Grand Forks	ND	58202		P
CRUMMY, Laurie	Red River High School	Grand Forks	ND	58201		P
CULBERTSON, Andrea	901 25th Ave NW	Minot	ND	58703		S
CURRENT, Robert W	1121 1st Ave N	Grand Forks	ND	58203		S
DAFOE, Arthur W	551 Third Street North East	Valley City	ND	58072	701 845 2439	E
DAHLEN, Gwen M	Human Nutrition Research Center	Grand Forks	ND	58202	701 795 8498	P
DAVIS, David G	Biosciences Research Laboratory	Fargo	ND	58105	701 239 1247	P
DELORME, Andre	Valley City State University	Valley City	ND	58072	701 845 7573	P
DIK, Mickie L	Moorhead State University	Moorhead	MN	56563		S
DINGA, Gustav P	Concordia College	Moorhead	MN	56560		E
DISRUD, Dennis T	413 Hillcrest Drive	Minot	ND	58703	701 839 3784	P
DOGGER, James R	P O Box 208	Gore	VA	22637	540 858 2613	P

DOLL, Mark A	University of North Dakota	Grand Forks	ND	58202		P
DRYER, Pamela J	1501 North 12th Street Box 2432	Bismarck	ND	58502	701 223 1844	P
DUTTENHEFNER, Kathy	ND Parks and Recreation Depart	Bismarck	ND	58504	701 328 5370	P
EDGERLY, Charles G M	1317 Eighth Avenue South	Fargo	ND	58103	701 235 5105	E
EIDE, John D	Northern Crop Science Laboratory	Fargo	ND	58105	701 239 1354	P
ELHARDT, Dale G	801 25th Street North West	Minot	ND	58701	701 839 7449	P
ELLINGSON, Jonathan	University of North Dakota	Grand Forks	ND	58202	701 777 2821	S
EPSTEIN, Paul N	University of North Dakota	Grand Forks	ND	58202		P
ERICKSON, J. Mark	St Lawrence University	Canton	NY	13617	315 379 5190	P
EULISS, Ned H	Northern Prairie Wildlife Res Ctr	Jamestown	ND	58401		P
FARNUM, Bruce W	3M Cottage Grove Center	Saint Paul	MN	55133	612 458 2268	P
FASTENAU, Daniel E	705 22nd Ave NW	Minot	ND	58703		S
FEIL, Vernon J	Biosciences Research Laboratory	Fargo	ND	58105	701 239 1236	P
FEIST, Susan A	Minot State University	Minot	ND	58702	701 839 7225	P
FENG, Yi	UND School of Medicine	Grand Forks	ND	58202		P
FILLIPI, Gordon M	United Hospital Microbiology Lab	Grand Forks	ND	58201	701 780-5134	P
FISK, Allen L	1122 Avenue B West	Bismarck	ND	58501	701 223 7447	E
FOSSUM, Guilford O	1828 Cottonwood Street	Grand Forks	ND	58201	701 775 7842	E
FOX, Carl	University of North Dakota	Grand Forks	ND	58202	701 777 4280	P
FRETLAND, Adrian	University of North Dakota	Grand Forks	ND	58202		S
FUNKE, Berdell R	North Dakota State University	Fargo	ND	58105	701 231 7846	P
GARVEY, Roy	North Dakota State University	Fargo	ND	58105	701 231 8697	P
GERADS, Jacquie R	Moorhead State University	Moorhead	MN	56563		S
GERLA, Phil	University of North Dakota	Grand Forks	ND	58202	701 777 3305	P
GILLIES, George T	University of Virginia	Charlottesville	VA	22901	804 924 3781	P
GOETTLER, Hans J	North Dakota State University	Fargo	ND	58105	701 231 8836	P
GROENEWOLD, Gerald H	Energy and Environment Res Ctr	Grand Forks	ND	58202	701 777 5131	P
GROTH, Larry D.	1801 College Drive N	Devils Lake	ND	58301		P
HAAS, Katherine	1037 Pinecrest Drive	Annapolis	MD	21403		P
HARTMAN, Joseph H	Energy and Environment Res Ctr	Grand Forks	ND	58203	701 777 2551	P
HASSETT, David J	Energy and Environment Res Ctr	Grand Forks	ND	58202	701 777 5192	P
HASTINGS, Michael	Dickinson State University	Dickinson	ND	58601		P
HATCHER, Emiko	UND School of Medicine	Grand Forks	ND	58202	701 777 2298	S
HEIDEL, Bonnie	Montana Natural Heritage Prog	Helena	MT	59620	406 444 0536	P
HEILMANN, Larry J	Biosciences Research Laboratory	Fargo	ND	58105	701 239 1301	P
HEIN, David W	UND School of Medicine	Grand Forks	ND	58202	701 777 4293	P
HEMMASI, Mohammad	University of North Dakota	Grand Forks	ND	58202	701 777 4592	P
HILL, Andrew	Saint Lawrence University	Canton	NY	13617		S
HOBBS, John T	200 15th Ave	Devils Lake	ND	58301		P
HOEPPNER, Jerome J	2518 Nineth Avenue North	Grand Forks	ND	58203		E
HOFFMANN, Mark	University of North Dakota	Grand Forks	ND	58202		P
HOGANSON, John W	North Dakota Geological Survey	Bismarck	ND	58505	701 328 9706	P
HOLLAND, Jean H	4686 Belmont Road	Grand Forks	ND	58201	701 775 0995	E
HOLLAND, F D Jr	University of North Dakota	Grand Forks	ND	58202	701 772 1622	E
HUBBARD, Trent D	211 Walnut Street, Apt 2	Grand Forks	ND	58201	701 772 5389	S
HUGO, Eric R	Dickinson State University	Dickinson	ND	58601	701 227 2069	P
HULLA, Janis	UND School of Medicine	Grand Forks	ND	58202	701 777 6222	P
HUNT, Janet R	Human Nutrition Research Center	Grand Forks	ND	58202	701 795 8328	P
HUNT, Curtiss D	Human Nutrition Research Center	Grand Forks	ND	58202	701 795 8423	P
INGVALSON, Diane K	Energy and Environment Res Ctr	Grand Forks	ND	58202		P
JACOBS, Francis A	1525 Robertson Court	Grand Forks	ND	58201	701 772 2447	E
JEGIER, Jolin A	North Dakota State University	Fargo	ND	58105		S
JENSEN, Bruce R	Jamestown College	Jamestown	ND	58405	701 252 3467	P
JOHANSEN, Dorothy	Mayville State University	Mayville	ND	58257	701 786 2301	P

JOHNSON, W Thomas	Human Nutrition Research Center	Grand Forks	ND	58202	701 795 8411	P
JOHNSON, Phyllis E	USDA/ARS Beltsville Area	Beltsville	MD	20705	301 504 5193	P
JOHNSON, Douglas H	Northern Prairie Science Center	Jamestown	ND	58401		P
JOHNSON, Jennifer A	2826 Hickory St NE	Fargo	ND	58102		S
JONES, Maureen	St. Lawrence University	Canton	NY	13617		S
JORDE, Dennis G	Patuxent Wildlife Research Center	Laurel	MD	20708	301-497-5652	P
KAFKA, Susan	Minnesota Academy of Science	St Paul	MN	55101	612 227 6361	P
KANNOWSKI, Paul	University of North Dakota	Grand Forks	ND	58202	701 777 2199	E
KANTRUD, Harold	Nothern Prairie Science Center	Jamestown	ND	58401	701 252 5363	P
KARNER, Frank R	University of North Dakota	Grand Forks	ND	58202	701 777 2811	P
KATHREIN, Melanie J	Dickinson High School	Dickinson	ND	58602	701 579 4631	P
KAYS, Glenn B	340 Old Saratoga Road	Garrevoort	NY	12831		S
KEEHR, Kay A	Human Nutrition Research Center	Grand Forks	ND	58202		P
KELLEY, Patricia	University of North Dakota	Grand Forks	ND	58202	701 777 2380	P
KEYS, Ross D	1836 Billings Drive	Bismarck	ND	58504	701 255 4211	P
KIESLING, Richard	Post Office Box 204	Fargo	ND	58107		E
KIHM, Allen J	Minot State University	Minot	ND	58707	701 858 3864	P
KILLINGBECK, James	ND Dept Health, Environ Eng	Bismarck	ND	58506	701 328 5188	P
KIRBY, Don	North Dakota State University	Fargo	ND	58105		P
KLOSTERMAN, Harold J	1437 12 Street North	Fargo	ND	58102	701 232 1141	E
KNULL, Harvey	University of North Dakota	Grand Forks	ND	58202	701 777 2786	P
KOCH, Frank	Bismarck State College	Bismarck	ND	58501		P
KOLSTOE, Ralph H	2200 South 29th Street Apt 515	Grand Forks	ND	58201	701 772 3972	E
KOTASKA, Cy	Sawyer Public School	Sawyer	ND	58781	701 624 5167	P
KOZLIAK, Evguenii I	University of North Dakota	Grand Forks	ND	58202		P
KRAFT, Donald J	Bemidji State University	Bemidji	MN	56601	218 755 2795	P
KRAFT, Kathy M	Jamestown College	Jamestown	ND	58405		P
KRALIK, Patricia	University of North Dakota	Grand Forks	ND	58202		P
KRESS, Warren D	North Dakota State University	Fargo	ND	58105	701 231 7145	E
KRUGER, Robert M	Mayville State University	Mayville	ND	58257	701 786 4804	P
KRUMENAKER, Joshua	University of North Dakota	Grand Forks	ND	58202	701 777 2289	S
KRUMM, Mark P	Minot State University	Minot	ND	58707		P
KRUPINSKY, Joseph M	Northern Great Plains Res Ctr	Mandan	ND	58554		P
KUIPERS, Gilbert	Valley City State University	Valley City	ND	58072		P
LAIRD, Wilson M	449 Florian Drive	Kerrville	TX	78028	210 257 4833	E
LAMBETH, David O	University of North Dakota	Grand Forks	ND	58202	701 777 3937	P
LARSON, Omer R	University of North Dakota	Grand Forks	ND	58202	701 777 4674	P
LARSON, Diane L	Northern Prairie Wildlife Res Ctr	Jamestown	ND	58401	701 252 5363	P
LAWSON, Shawn W	1240 Glacial Drive #4	Minot	ND	58703		S
LEEKS, Barry	630 N 6th St	Grand Forks	ND	58203		S
LEGGE, Jean	Litchville-Marion High School	Valley City	ND	58072	701 845 4762	P
LINCOLN, Terry	Dakota Zoological Society	Bismarck	ND	58502		P
LINDLEY, James A	North Dakota State University	Fargo	ND	58105	701 231 7273	P
LINZ, George M	North Dakota State University	Fargo	ND	58105	701 231 7054	P
LORENZ, Russell J	1924 North Grandview Lane	Bismarck	ND	58501	701 223 3421	P
LOW, Frank N	2511 Saint Charles Avenue	New Orleans	LA	70130		E
LOWE, Stephen L	Minot State University	Minot	ND	58707	701 858 3082	P
LOWE, Margaret J	Minot State University	Minot	ND	58707		P
LUDLOW, Douglas K	518 Princeton	Grand Forks	ND	58203		P
MacCARTHY, Ronald F	University of North Dakota	Grand Forks	ND	58202	701 777 4424	P
MADHOK, Om	1304 13th Ave NW	Minot	ND	58703		P
MALLIK, Sanku	University of North Dakota	Grand Forks	ND	58202	701 7772495	P
MANSKE, Llewellyn L	Dickinson Research Center	Dickinson	ND	58601	701 227 2348	P
MARKELL, Clark	Minot State University	Minot	ND	58707	701 858 3069	P

MARTIN, Paula J.	Dickinson State University	Dickinson	ND	58601		P
MARTSOLF, John	UND School of Medicine	Grand Forks	ND	58202	701 777 4277	P
MASON, Harry	Jamestown Traffic Safety Task Force	Jamestown	ND	58402	701 252 1247	P
McCARTHY, Greg	North Dakota State University	Fargo	ND	58105	701 231 7193	P
McCOLLOR, Donald P	Energy and Environment Res Ctr	Grand Forks	ND	58202	701 777 5121	P
McCOY-BROWN, Carol	U S Forest Service	Billings	MT	59103		P
McMAHON, Kenneth J	North Dakota State University	Fargo	ND	58105	701 231 7668	E
McNAIR, Ronald E	North Dakota State University	Fargo	ND	58105	701 231 8028	P
MEARTZ, Paul D	Mayville State University	Mayville	ND	58257	701 786 4809	P
MELDRUM, Alan	512 Columbia Road North	Grand Forks	ND	58203	701 772 1166	E
MERSCH, Dawn K.	615 N 39th St, Apt 308C	Grand Forks	ND	58203		S
MICHELSEN, Kim G	Human Nutrition Research Center	Grand Forks	ND	58202	701 795 8357	P
MINETTE, Ray	209 Fourth Street South West	Rugby	ND	58368	701 776 6484	E
MITCHELL, Earl N	220 Glenhill Lane	Chapel Hill	NC	27514		E
MOEN, R J	UND School of Medicine	Grand Forks	ND	58202		S
MOEN, Janet	University of North Dakota	Grand Forks	ND	58202		P
MOTT, Daniel J	Dickinson State University	Dickinson	ND	58601	701 227 2111	P
MUNSKI, Douglas	University of North Dakota	Grand Forks	ND	58202	701 777 4591	P
MUNSKI, Laura	University of North Dakota	Grand Forks	ND	58202	701 772 8207	P
MURPHY, Michelle PU	University of North Dakota	Grand Forks	ND	58202		S
NAVID, Ali	University of North Dakota	Grand Forks	ND	58202		S
NELSON, C N	North Dakota State University	Bottineau	ND	58318		E
NELSON, Robert M	North Dakota State University	Fargo	ND	58105	701 231 7619	P
NEWTON, Wes	National Biological Service	Eckelson	ND	58432	701 646 6703	P
NGUYEN, Hugh V	UND School of Medicine	Grand Forks	ND	58202		S
NIELSEN, Forrest H	Human Nutrition Research Center	Grand Forks	ND	58202	701 795 8456	P
NOLAN, Lisa	North Dakota State University	Fargo	ND	58105		P
NOVY, Rich	North Dakota State University	Fargo	ND	58105		P
NYRE, Paul E	Central Grasslands Research	Streeter	ND	58483	701 424 3606	P
OAKLAND, Laura	Pioneer Trails Regional Muse	Bowman	ND	58623	701 523 3625	P
OBERPRILLER, Jean	University of North Dakota	Grand Forks	ND	58202		P
OLSON, Mark D.	University of North Dakota	Grand Forks	ND	58202		P
OLSON, Tom A	Route 1, Box 92	Jamestown	ND	58401		P
ORR, Paul H	USDA Potato Research Laboratory	East Grand Forks	MN	56721	218 773 0162	P
OSTLIE DUNN, Tana	2499 Estabrook Dr	Grand Forks	ND	58201		S
OWEN, John B	1118 Reeves Drive	Grand Forks	ND	58201	701 775 8089	E
OWENS, Thomas C	University of North Dakota	Grand Forks	ND	58202	701 777 4244	P
PALMATEER, Brett	R D #1 Bonney Hill Road	Hamilton	NY	13346		S
PANSEGRAU, Paul D	Dakota Gassification Company	Beulah	ND	58523	701 873 6471	P
PARSON, Tiffany	2350 30th Ave S #624	Grand Forks	ND	58201		S
PEARSON, Dean A	Pioneer Trails Museum	Bowman	ND	58623	701 523 3625	P
PENLAND, James G	Human Nutrition Research Center	Grand Forks	ND	58202	701 795 8471	P
PERKINS, Dexter	University of North Dakota	Grand Forks	ND	58202	701 777 2811	P
PFISTER, Philip C	North Dakota State University	Fargo	ND	58105	701 232 5407	E
PFLUGHOEFT-HASSET, Debra	Energy and Environment Res Ctr	Grand Forks	ND	58202	701 777 5261	P
PHILLIPS, Karen A	North Dakota State University	Fargo	ND	58105		S
PIERCE, Ken S.	1465 14th St W #1	Dickinson	ND	58601		P
POELLOT, Rhonda	Human Nutrition Research Center	Grand Forks	ND	58202	701 795 8406	P
POST, John S	230 Bedford Road	Greenwich	NY	05831		S
PRUNTY, Lyle	North Dakota State University	Fargo	ND	58105		P
QIANGRONG, Liang	University of North Dakota	Grand Forks	ND	58202		S
QUICK, Amy	7301 Fremont Ave S	Richfield	MN	55423	612 866 2143	P
RADA, Jody	University of North Dakota	Grand Forks	ND	58202		P
RAO, Marepalli B	North Dakota State University	Fargo	ND	58105	701 231 8178	P

RAWAT, Banmali	University of Nevada, Reno	Reno	NV	89557	702 784 6927	P
RAWSON, Jenny	North Dakota State University	Fargo	ND	58105	701 231 7402	P
RAY, Paul D	UND School of Medicine	Grand Forks	ND	58202	701 777 3937	P
REID, John R	University of North Dakota	Grand Forks	ND	58202	701 777 2131	P
RIEKE, Garl	University of North Dakota	Grand Forks	ND	58202		P
RIES, Ronald E	908 Second Avenue NW	Mandan	ND	58554	701 663 7335	P
ROGERS, David A	North Dakota State University	Fargo	ND	58105	701 231 7216	P
ROGLER, George A	1701 Monte Drive	Mandan	ND	58554		E
ROYER, Ron	Minot State University	Minot	ND	58707	701 858 3209	P
RUDESILL, James T	1318 Twelveth Street North	Fargo	ND	58102	701 235 4629	E
RUIT, Kenneth	University of North Dakota	Grand Forks	ND	58202		P
RUSH, David B	812 North Fourth Street	Grand Forks	ND	58203		S
SAINI-EIDUKAT, Bernhardt	North Dakota State University	Fargo	ND	58105	701 231 8785	P
SALTMARSH, Jennifer	2867 19th Ave S #10	Grand Forks	ND	58201	701 795 9199	S
SCHAEFER, Nancy O	Pioneer Trail Regional Museum	Bowman	ND	58623	701 523 5302	P
SCHERER, Steve	2831-F 20th Ave S	Grand Forks	ND	58201		S
SCHMID, Thomas	109 Durango Drive	Burlington	ND	58722	701 838 6032	P
SCHMIDT, Claude H	1827 North Third Street	Fargo	ND	58102	701 293 0365	E
SCHMITZ, Lowell E	Moorhead State University	Moorhead	MN	56563		S
SCHNABEL, Shiloh	Minot State University	Minot	ND	58707		S
SCHNAIBLE, Scott E.	500 Parkway Dr. #D	Burlington	ND	58722		S
SCHNEIDER, Fred	University of North Dakota	Grand Forks	ND	58202		P
SCHRADER, Stephanie	709 10th St NW	Minot	ND	58703		S
SCHWERT, Donald P	North Dakota State University	Fargo	ND	58105	701 231 7496	P
SCOBY, Donald R	North Dakota State University	Fargo	ND	58105	701 235 3389	E
SEDIVEC, Kevin	North Dakota State University	Fargo	ND	58105	701 231 7647	P
SEVERSON, Roland	2682 Catalina Drive	Grand Junction	CO	81506		E
SHAFFER, Terry L	2205 Fourth Street North East	Jamestown	ND	58401	701 251 2399	P
SIDERS, William A	1105 South Twenty Second St	Grand Forks	ND	58201	701 746 8921	P
SIMS, Roger L	5050 Fifth Avenue North	Grand Forks	ND	58203	701 775 8007	P
SLEEPER, Bayard P	Post Office Box 2236	Paulsbo	WA	98370		E
SMITH, Glenn S	3140 North Tenth Street	Fargo	ND	58102	701 235 6785	E
SMITH, Heidi S	Minot State University	Minot	ND	58707	701 838 0115	S
SMITH, Terry	University of North Dakota	Grand Forks	ND	58202		S
SMITH, Donald A	North Dakota State University	Fargo	ND	58105	701 231 7401	P
SMOLIAKOVA, Irina P	University of North Dakota	Grand Forks	ND	58201		P
SNOOK, Theodore	343 Sheridan Road	Racine	WI	53403	414 552 8781	E
SOUBY, Armand M	103 Nichols	San Marcos	TX	78666		E
SPANIER, Jon G	UND School of Medicine	Grand Forks	ND	58202	701 777 2750	P
STARR, Eileen M	Valley City State University	Valley City	ND	58072	701 845 7522	P
STATLER, Glen D	North Dakota State University	Fargo	ND	58105	701 231 7058	P
STEGEMAN, Jamie	1806 29th St. Circle S.	Moorhead	MN	56560	218 236 2576	S
STEWART, James A	Pembroke	Ontario	CANADA	K8A 1X2	613 732 8462	E
STICKLER, Joseph C	Valley City State University	Valley City	ND	58072	701 845 1848	P
STINNETT, Henry O	UND School of Medicine	Grand Forks	ND	58202	701 777 3955	P
STOAKS, Ralph	5888 Our Way	Citrus Heights	CA	95610	916 965 4045	P
STOCKRAHM, Donna M Bruns	Moorhead State University	Moorhead	MN	56563	218 236 2576	P
SUGIHARA, James	1001 Southwood Drive	Fargo	ND	58103	701 235 8266	E
SUKALSKI, Katherine A	University of North Dakota	Grand Forks	ND	58202	701 777 4049	P
SUMMERS, Lawrence	1019 Porter Avenue # 121	Bismarck	ND	58501		E
SWANSON, Richard J	Rural Route 1 Box 102A	Richville	MN	56576	218 758 2385	P
SWITALSKI, Ann M.	105 Tangley Rd #4	Minot AFB	ND	58704		S
TARQUINIO, Robert K.	215 Hancock	Grand Forks	ND	58202	701 777 8329	S
THOMASSON, Kathryn A	University of North Dakota	Grand Forks	ND	58202	701 777 3199	P

THOMPSON, Michael B	2208 Crescent Drive	Minot	ND	58703	701 839 6305	P
THOMPSON, Peter	North Dakota State University	Fargo	ND	58105	701 231 8188	P
TODD, Robert G	221 Seventh Avenue West	Dickinson	ND	58601	701 225 5056	P
TOMANEK, Debra	North Dakota State University	Fargo	ND	58105	701 231 7336	P
TOOM, Dennis	University of North Dakota	Grand Forks	ND	58202		P
TSCHAEKOFSKE, Scott	University of North Dakota	Grand Forks	ND	58202		S
ULMER, Michael G	202 East Divide	Bismarck	ND	58501	701 258 6454	P
URLACHER, Kenneth	Route 2 Box 25	New England	ND	58647	701 579 4414	S
UTHUS, Eric O	Human Nutrition Research Center	Grand Forks	ND	58202	701 795 8382	P
UTTER, Rodney	North Dakota State University	Fargo	ND	58105	701 231 7561	P
VAN ALSTINE, James B	University of Minnesota, Morris	Morris	MN	56267	320-589-6313	P
VANDERPOOL, Richard A	Human Nutrition Research Center	Grand Forks	ND	58202	701 795 8416	P
VARI, Richard C.	University of North Dakota	Grand Forks	ND	58202		P
WALLA, James	North Dakota State University	Fargo	ND	58105	701 231 7069	P
WALSH, Robert G	Rural Route 6 Box 124 CC Acres	Minot	ND	58701		E
WALSH, Nancy J	3415 Twentieth Avenue So #310	Grand Forks	ND	58201	701 662 4629	S
WANEK, Wallace J	16901 Irvine Avenue NW	Bemidji	MN	56601	218 243 2245	P
WATTERS, Bryan K	Moorhead State University	Moorhead	MN	56563		S
WEBSTER, John R.	912 West Central Ave	Minot	ND	58701		P
WEISSER, Wilber O	55 Parkview Circle	Grand Forks	ND	58201	701 772 4013	E
WELLMAN, Dawn	2120 Library Lane Apt 303	Grand Forks	ND	58201		S
WHITE, David G	North Dakota State University	Fargo	ND	58105		P
XU, Bo	University of North Dakota	Grand Forks	ND	58202		P
ZHANG, Mingyu	UND School of Medicine	Grand Forks	ND	58202		S

membership list as of March 23, 1997

E, Emeritus
P, Professional
S, Student

A

Achen, VR 210
Anderton, JB 62*
Audette, J 146, 184
Avery, KK 197

B

Bai, Y 181
Beck, DL 161*
Becker, AM 194
Becker, WK 194
Berkas, WR 28
Blake, MJ 179
Bluemle, JP 10
Borg, KE 149
Borgerding, AJ 162*
Borgland, SL 182
Bozek, MA 211
Bras, A 183*
Buckley, AR 149, 168, 174, 179
Buckley, DJ 149, 168, 174, 179

C

Carlson, EC 146, 176, 184*, 221, 222
Casiro, OG 208
Chastain, CJ 223
Christopherson, DM 185*
Clausen, EN 186*, 187*
Cooley, AM 194
Crawford, G 151
Crawford, RD 151
Crummy, LA 188*
Current, RW 162*

D

Davis, BB 199
Deitz, AC 159, 164, 191, 199
Dockter, BA 137*
Dolhun, BA 189*
Dolinsky, V 190*
Doll, MA 159, 164, 169, 191*, 199

E

Ellingson, JB 192*, 193*
Epstein, PN 169, 170, 184, 205, 224
Erickson, JM 203

F

Feng, Y 163, 194*
Fox, PW 146*
Fretland, AJ 159, 163*, 164, 194

G

Geiger, JD 189, 198
Gerla, PJ 217
Goebel, DR 217
Goodman, LR 58*
Goralski, KB, 195*
Gosnold, WD 177, 196*
Gray, K 159, 164*

H

Hall, CB 209
Hammond, RT 117*
Hartman, JH 161
Haselton, JR 197*
Hassett, DJ 130, 133*
Hatch, GM 190, 218
Haugen, J 111*
Haughey, NJ 198*
Hayes, RB 159, 164
Hein, DW 159, 163, 164, 169, 191, 194, 199*
Hemmasi, M 75*
Henriksen, MJ 106*
Hickok, F 81*
Hoganson, JW 166
Holden, CP 189
Hollevoet, RA 6*
Holm, JE 157
Hubbard, TD 200*
Huber, D 147*
Hughes, C 155
Hulla, J 167
Hunt, CD 181, 188, 204
Hunt, JR 201*
Hustoft, P 143
Hyjek, DH 202*

I

Idso, JP 188, 204
Ivey, MA 171

J

Jacobson, K 216
Jensen, K 58
Jiang, W 164, 191
Johnson, DH 102
Johnson, JA 148*
Johnson, JD 165*
Jones, MA 203*

K

Kays, GB 166*

Keehr, KA 204*
Kelley, PH 166
Kelsch, SW 148
Kessler, T 75
Kissner, R 167*
Klapprodt, L 50*
Klevay, LM 185
Knight, B 143*
Kochendoerfer, SK 149*
Kozliak, EI 173, 175
Kralik, PM 205*, 224
Krumenacker, J 149, 168*

L

Laducer, S 214
Lai, K-W 117
Lakshmi, VM 199
Lambeth, DO 165, 171
Lee, KJ 194
Leeks, B 150*
Leff, MA 169*
Legler, T 154
Leland, HV 28*
Lent, RM 34, 45*
Liang, Q 170*
Lowe, SL 206*
Lukaski, HC 209, 220
Lura, CL 14, 18*

M

Mallik, S 152, 153
Mangat, R 218*
Manz, OE 126*
McClarty, G 218
McCormack, JT 207
McKee, Y 215
Mehus, JG 171*
Mersch, DK 207*
Meyers, AFA 208*
Michelsen, KG 209*
Milavetz, BI 171
Milne, DB 212
Minuk, GY 208
Moen, JK 67*
Moen, M 147
Mount, BA 210*
Mudivarthy, S 92*, 97
Munski, DC 70*
Murphy, MP 172*

N

Nath, A 189, 198
Navid, A 173*
Newbrey, MG 211*
Newman, SM Jr 181*, 188, 209
Nguyen, H 149, 157, 174*
Nielsen, FH 212*
Norton, MA 157
Norton, T 143, 144

O

Oberpriller, JC 207
Olson, MD 202
Ostlie Dunn, TL 175*

P

Parkinson, FE 182
Parson, TAS 151*
Pearson, DA 213*
Perry, CA 214*
Perryman, W 215*
Pflughoeft-Hassett, DF 133, 137

R

Rada, JA 146, 210, 214, 215, 221
Radu, V 164
Raghib, TO 168
Rannie, WF 34
Rao, MB 87, 92, 97*
Reid, JR 10*, 200
Ressler, MJ 176*
Richardson, JL 14*, 18
Ricke, GK 216*
Rieke, JL 144*
Ruit, K 215
Rush, DB 217*
Rusnak, A 218
Rustan, TD 191, 194, 199
Rylance, JR 87*

S

Safratowich, M 144
Saltmarsh, J 152*
Samson, WK 172
Sando, T 53*
Sargeant, GA 102*
Scherer, SD 153*
Schmidt, WL 177*, 196
Schmitz, LE 219
Schneider, F 20*
Schwehr, HL 154*
Shabb, JB 206
Shianna, K 178*
Shuler, TR 185

Siders, WA 220*
Sitar, DS 183, 195
Slover, M 214
Spanier, J 178
Spencer, MK 221*
Stegeman, JL 219*
Steinwand, TR 24*
Stewart, A 130*, 137
Stockrahm, DM Bruns 223
Sundhagen, RK 117
Swinscoe, JC 222*
Szczys, P 155*

T

Tessmann, P 147
Todhunter, PE 29*
Toom, D 20
Tschaekofske, S 156*
Tu, H 197

V

Vari, RC 172, 197
Vecchia, AV 34, 40*

W

Walter, BM 197
Watters, BK 223*
Wawryk, RJ 157*
Wellman, DM 158*
White, DG 147
Wiche, GJ 34*, 40, 45
Wilkie, TR Sr 159*
Williams, SH 122*

X

Xiong, W 182
Xu, B 205, 224
Xu, F 218*

Z

Zenser, TV 199
Zhang, M 149, 179*
Zito, CA 201

*Presenting author

Proceedings of the NORTH DAKOTA Academy of Science

89th Annual Meeting

September 1997 Volume 51, Supplement 1

Proceedings of the North Dakota Academy of Science (ISBN 0096-9214)

Correspondence concerning subscriptions (standing orders), as well as instructions for authors and other related matters, should be directed to:

Office of the Secretary-Treasurer
North Dakota Academy of Science
PO Box 7081
Grand Forks, North Dakota 58202
USA

Funding for publishing this supplemental issue of the Proceedings of the North Dakota Academy of Science was made possible by a generous gift from the Bush Foundation which is working in partnership with the Otto Bremer Foundation for the recovery of communities in the Red River Valley.

Printed by Knight Publishing
Fargo, North Dakota

PROCEEDINGS
OF THE
NORTH DAKOTA ACADEMY OF SCIENCE

Volume 51, Supplement 1 September 1997

SYMPOSIUM ON THE RED RIVER FLOOD OF 1997
INVOLVING SCIENCE IN FUTURE WATERSHED MANAGEMENT DECISIONS

NORTH DAKOTA ACADEMY OF SCIENCE
(Official State Academy; Founded December 1908)

1996–1997

The Red River Water Management Consortium of the Energy & Environmental Research Center is pleased to co-sponsor a symposium offering public access to scientific perspectives on events associated with the Red River flood of 1997.

89th Annual Meeting

September 15-16, 1997

Grand Forks, North Dakota

SYMPOSIUM ON THE RED RIVER FLOOD OF 1997
INVOLVING SCIENCE IN FUTURE WATERSHED MANAGEMENT DECISIONS

Contributors 4

Introduction

Involving Science in Future Watershed Management Decisions 5
Gale Mayer – Energy & Environmental Research Center Red River Water Management Consortium

Geologic and Historic Conditions of the Watershed

Geologic setting and prehistoric record of the Red River Valley 6
Ken Harris – Minnesota Geological Survey

Archaeology and flood deposits at The Forks, Winnipeg, Manitoba, Canada 12
Sid Kroker – Quaternary Consultants

Factors affecting flooding in the Red River Valley 17
John Bluemle – North Dakota Geological Survey

Quantifying Existing Conditions of the Watershed

UNET unsteady flow models for the Red River of the North 21
Terry Zien – U.S. Army Corps of Engineers

An overview of the Red River valley winter of 1996–1997 26
Leon Osborne Jr. – University of North Dakota

Water quality in the Red River of the North during the spring flood of 1997 30
Mark Brigham and David Lorenz – U.S. Geological Survey

Flood protection in the Netherlands 31
Jos Kuijpers and Jan Janse – The Netherlands Directorate-General for Public Works and Water Management

Predicting the Response of the Watershed to Proposed Modifications

Flood of the century and flood management 37
Todd Sando – North Dakota State Water Commission

Restoration of bottomland forests: Challenges and opportunities 40
John Ball – South Dakota State University

The hard path and the soft path to flood protection 44
Dexter Perkins – University of North Dakota

International Aspects of Watershed Management

Preventing and resolving disputes: The International Joint Commission's role under the Boundary Waters Treaty 48
Frank Bevacqua – International Joint Commission

Overview

The ever present chance of flooding 51
Joseph Hartman – Energy & Environmental Research Center

Dr. John J. Ball, Professor
South Dakota State University, Department of Horticulture, Forestry, Landscape & Parks, Box 2140a, Brookings, SD 57007; (605) 688-4737; e-mail – jball@doa.state.sd.us

Mr. Frank Bevacqua, Public Information Officer
International Joint Commission, 1250 23rd Street NW, Suite 100, Washington, DC 20440; (202) 736-9024; e-mail – bevacquaf@ijc.org.inter.net

Dr. John P. Bluemle, Director
North Dakota Geological Survey, 600 East Boulevard Avenue, Bismarck, ND 58505; (701) 328-8000

Mr. Mark E. Brigham, C.E., Environmental Engineer
U.S. Geological Survey, 2280 Woodale Drive, Mounds View, MN 55112; e-mail – mbrigham@usgs.gov

Dr. Kenneth L. Harris, Geologist
Minnesota Geological Survey, 2642 University Avenue, St. Paul, MN 55114; (612) 627-4280; e-mail – harri015@maroon.tc.umn.edu

Dr. Joseph H. Hartman (Commentator), Geologist
Energy & Environmental Research Center, University of North Dakota, 15 North 23rd Street, Grand Forks, ND 58203; (701) 777-2551; e-mail – jhartman@plains.nodak.edu

Dr. Jan C. Janse, P.E., Senior Advisor Water Management Studies
The Netherlands Directorate-General for Public Works and Water Management, South Holland Department, Postbus 556, Boompjes 200, 3000 AN Rotterdam, The Netherlands; e-mail – j.c.janse@dzh.rws.minvenw.nl

Mr. Sid Kroker, Archeologist
Quaternary Consultants, 130 Fort Street, Winnipeg, Manitoba, Canada R3C 1C7; (204) 944-8325; e-mail – skroker@mb.sympatico.ca

Dr. Jos Kuijpers, P.E., Head of Water Management Studies and Policy Development
The Netherlands Directorate-General for Public Works and Water Management, South Holland Department, Postbus 556, Boompjes 200, 3000 AN Rotterdam, The Netherlands; 011-31-10-402-6351

Mr. David L. Lorenz, C.E., Hydrologist
U.S. Geological Survey, 2280 Woodale Drive, Mounds View, MN 55112; (612) 783-3271; e-mail – lorenz@usgs.gov

Dr. Gale Mayer (Moderator), Senior Research Manager
Energy & Environmental Research Center Red River Water Management Consortium, University of North Dakota, 15 North 23rd Street, Grand Forks, ND 58203; (701) 777-5108; e-mail – gmeyer@eerc.und.nodak.edu

Dr. Leon F. Osborne, Jr., Director
Regional Weather Information Center, University of North Dakota, PO Box 9007, Grand Forks, ND 58202; (701) 777-2479; e-mail – leono@rwic.und.nodak.edu

Dr. Dexter Perkins, Professor
University of North Dakota Department of Geology and Geological Engineering, PO Box 8358, Grand Forks, ND 58202; (701) 777-2991; e-mail – dexter_perkins@mail.und.nodak.edu

Mr. Todd Sando, P.E., Director
Division of Water Development, North Dakota State Water Commission, 900 East Boulevard Avenue, Bismarck, ND 58505; (701) 328-2752; e-mail – tsando@water.swc.state.nd.us

Mr. Terry R. Zien, P.E., Senior Hydraulic Engineer
U.S. Army Corps of Engineers, St. Paul District, 190 5th Street East, St. Paul, MN 55101; (612) 290-5714; e-mail – terry.r.zien@usace.army.mil

INVOLVING SCIENCE IN FUTURE WATERSHED MANAGEMENT DECISIONS

Gale G. Mayer
Energy & Environmental Research Center, University of North Dakota
15 North 23rd Street, Grand Forks, North Dakota 58203

On behalf of the University of North Dakota Energy & Environmental Research Center (EERC), we are pleased to cosponsor the Symposium on the Red River Flood of 1997 with the North Dakota Academy of Science. The theme for this symposium is "Involving Science in Future Watershed Management Decisions."

The flood of 1997 was the most culturally destructive event to impact the Red River of the North Basin in recorded history and affected communities in South Dakota, North Dakota, Minnesota, and Manitoba. Damages in the billions of dollars resulted from flooding of rural and urban communities and losses to agriculture and industry. In addition, the flooding resulted in the largest per capita evacuation of people in the history of the United States. This temporary relocation of approximately 75,000 people seriously impacted the resources of other communities throughout the upper Midwest region of the United States.

The magnitude of this disaster has inspired the compassion of people throughout the United States and the world. Assistance has been generously offered to help rebuild our communities and protect them from future flood events. Some of this assistance has been in the form of money or necessary supplies needed during the rebuilding effort. Other assistance has been in the form of expertise required to plan for a secure future. This symposium is an excellent example of the response from the scientific community. The scientists we will be hearing from today are experts in their fields and have willingly contributed their time to this effort.

In 1996, the EERC and stakeholders in the Red River of the North Basin teamed to develop the Red River Water Management Consortium (RRWMC) to find economical, practical, and timely solutions to water supply and water quality issues. This program brings the latest technical and scientific resources to bear in addressing important issues for the region. A recent meeting of this group resulted in the addition of a task on flood-related issues. Following is a list of some of needs discussed:

- Evaluation of the causes of 1997 flood event
- Local input on flood forecasting
- Public education on the significance and interpretation of forecasts
- Assessment of potential contribution of Devils Lake discharges to flooding on the Red River
- Evaluation of flood hazard mitigation options
- Determination of environmental impacts of the disaster
- Evaluation of infrastructure issues regarding the protection of basic health and human services
- Assessment of potential economic impacts to rural and urban areas

This symposium on the flood of 1997 furthers the effort to bring together the scientific community into the decision-making process on watershed management for the basin. The initial presentations give us an overview of the geological setting of the Red River of the North Basin, discussing historical trends and the potential for future flooding. The second set of presentations focuses on the existing condition of the watershed and factors pertinent to the flooding in 1997. Flood hazard mitigation options are also discussed during this session. The third session includes presentations on flood management and the pros and cons of various management options from a scientific perspective. The symposium concludes with a presentation by the International Joint Commission (IJC). The IJC has been mandated by the President of the United States to determine the causes and effects of the 1997 flood in the Red River of the North Basin and to make recommendations on means to reduce, mitigate, and prevent harm from future flooding.

The flood of 1997 has changed our perspective on the potential for flooding within this watershed. This flood affected not only the Red River, but many of its tributaries. In addition, overland flooding contributed to much of the damage observed. The magnitude of this flood event raises the question of how often floods can be expected to occur within the basin and their potential magnitude. It is imperative that we understand the geological setting of the basin and the factors that control flooding so that we can avoid recurrences of the devastation of 1997. Only by involving the scientific community in the watershed management decision-making process will we be able to accomplish this objective.

GEOLOGY OF THE SOUTHERN PART OF THE LAKE AGASSIZ BASIN

Kenneth L. Harris
Minnesota Geological Survey
2642 University Avenue, St. Paul, Minnesota 55114

INTRODUCTION

The Red River Valley as we know it today has been shaped by millions of years of geologic processes that have eroded and deposited sediment. The sediment at the surface was deposited in Glacial Lake Agassiz about 9000 years ago. Lake Agassiz was the most recent of many proglacial lakes that have occupied the basin. The Lake Agassiz basin was eroded by seven major glaciations that sent ice lobes southward on a course controlled largely by bedrock.

Recently completed geologic mapping and stratigraphic studies in the southern part of the basin were combined with previous work to provide insight into the geologic history of the basin. This compilation shows a strong correlation between the areal distribution of lithostratigraphic units (tills) and geomorphologic features such as ice margins, compaction ridges, tunnel valleys, and tunnel valley fans (1,2,3)

GEOLOGIC SETTING

Pre-Quaternary Geology

The southern Lake Agassiz basin is located on the southwestern edge of a large, stable mass of Precambrian igneous and metamorphic rock known as the Canadian Shield (Figure 1). The Canadian Shield is the stable core of the North American continent. The rocks that form the shield are estimated to be as old as 3.6 billion years (Ga), among the oldest rocks on the planet (4).

During the Paleozoic Era (about 590 to 248 million years ago [Ma]), marine sediments (lime mud, sand, silt, clay, and evaporite minerals) were deposited to the west in the Williston Basin of North Dakota. In time, these sediments formed rocks (limestone, dolostone, sandstone, shale, and salt). These Paleozoic rocks originally extended east into Minnesota. However, subsequent erosion thinned or removed all Paleozoic rock on the eastern edge of the Williston Basin except for a remnant that extends into the extreme northwestern part of the Minnesota (5,6) (Figure 1).

During the Mesozoic Era (about 248 to 65 Ma) marine and marginal-marine sediments (lime mud, sand, silt, clay, and organic debris) were again deposited in the basin. Mesozoic sediments are thought to have extended throughout most of western Minnesota. Subsequent erosion removed most of these rocks, but Cretaceous (about 146 to 65 Ma) sandstones and shales are present in the subsurface of the western and southern parts of the basin (Figure 1).

The Cenozoic Era (65 to 0 Ma) is divided into the Tertiary Subera (65 to 2 Ma) and the Quaternary Subera (2 to 0 Ma). Tertiary rocks have not been mapped in the southern part of the Lake Agassiz basin (7), but the entire area is covered by Quaternary sediment.

Quaternary Geology

Pleistocene. The Quaternary Subera is divided into the Pleistocene Epoch (2 to 0.01 Ma) and the Holocene Epoch (0.01 to 0 Ma). During the Pleistocene, the climate oscillated between cold glacial and warm interglacial climates. Glacial ice covered most of North Dakota and Minnesota many times, and periods of glaciation were separated by warm interglacial episodes. Glacier, lake, and river sediment was deposited each time a glacier advanced into the area and melted. All of the surface sediment in the southern part of the Lake Agassiz basin is Quaternary in age.

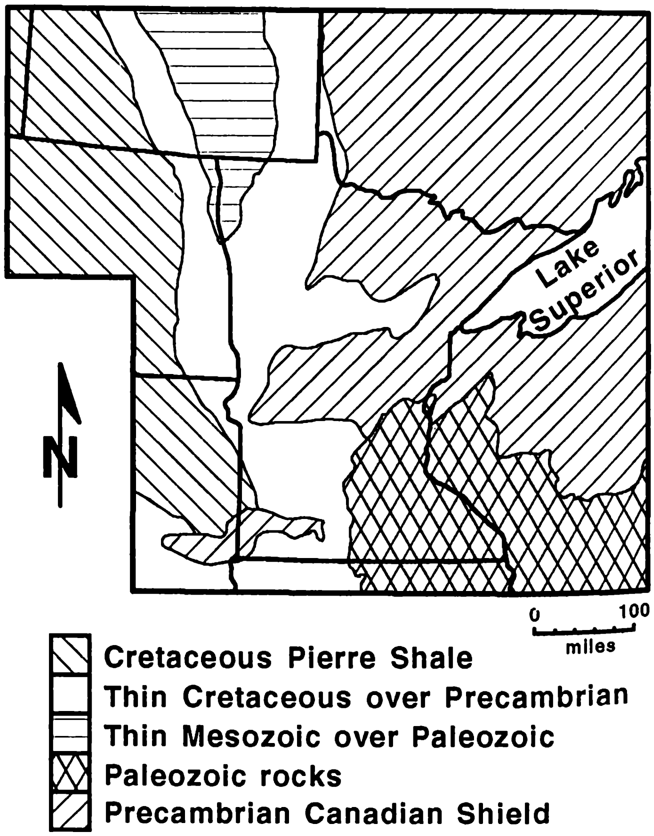


Figure 1. Generalized bedrock geology of the Upper Midwest

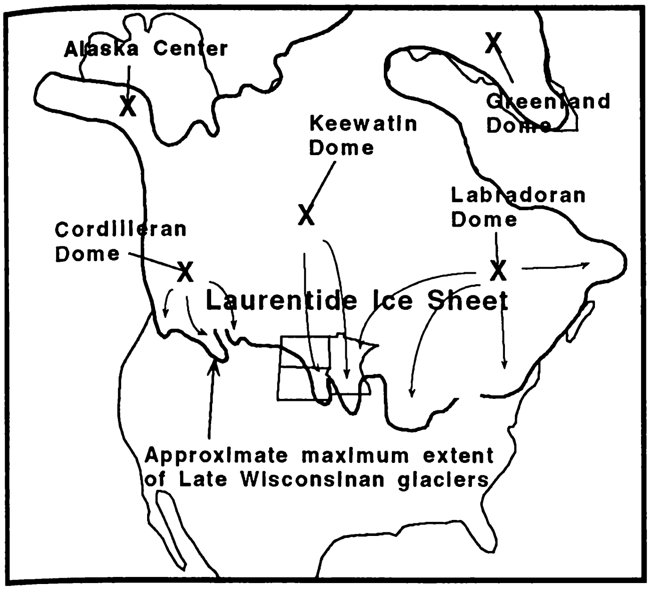


Figure 2. Approximate maximum extent of the Laurentide ice sheet about 15 ka. Arrows indicate possible flow paths of ice lobes.

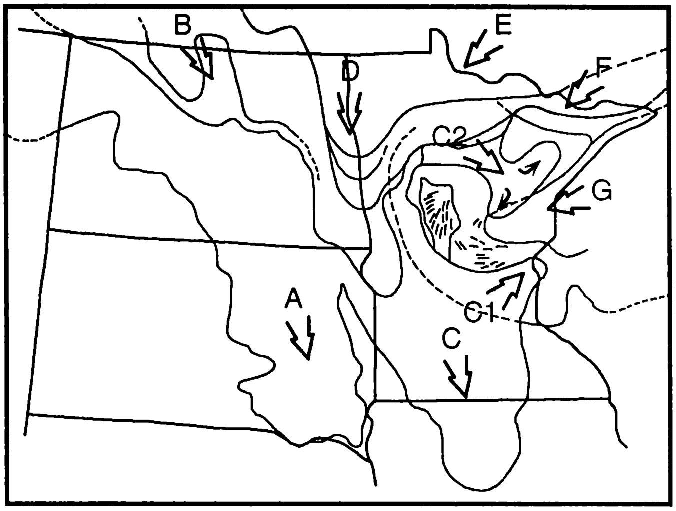


Figure 3. Major ice lobes and sublobes in the upper Midwest. Dashed lines indicate buried of uncertain boundaries. **Lobes: A.** James lobe; **B.** Souris lobe; **C.** Des Moines lobe; **C1.** Grantsburg sublobe; **C2.** St. Louis sublobe; **D.** Red River lobe; **E & F.** Rainy lobe; and **G.** Superior lobe. Modified from Clayton and Moran, 1982.

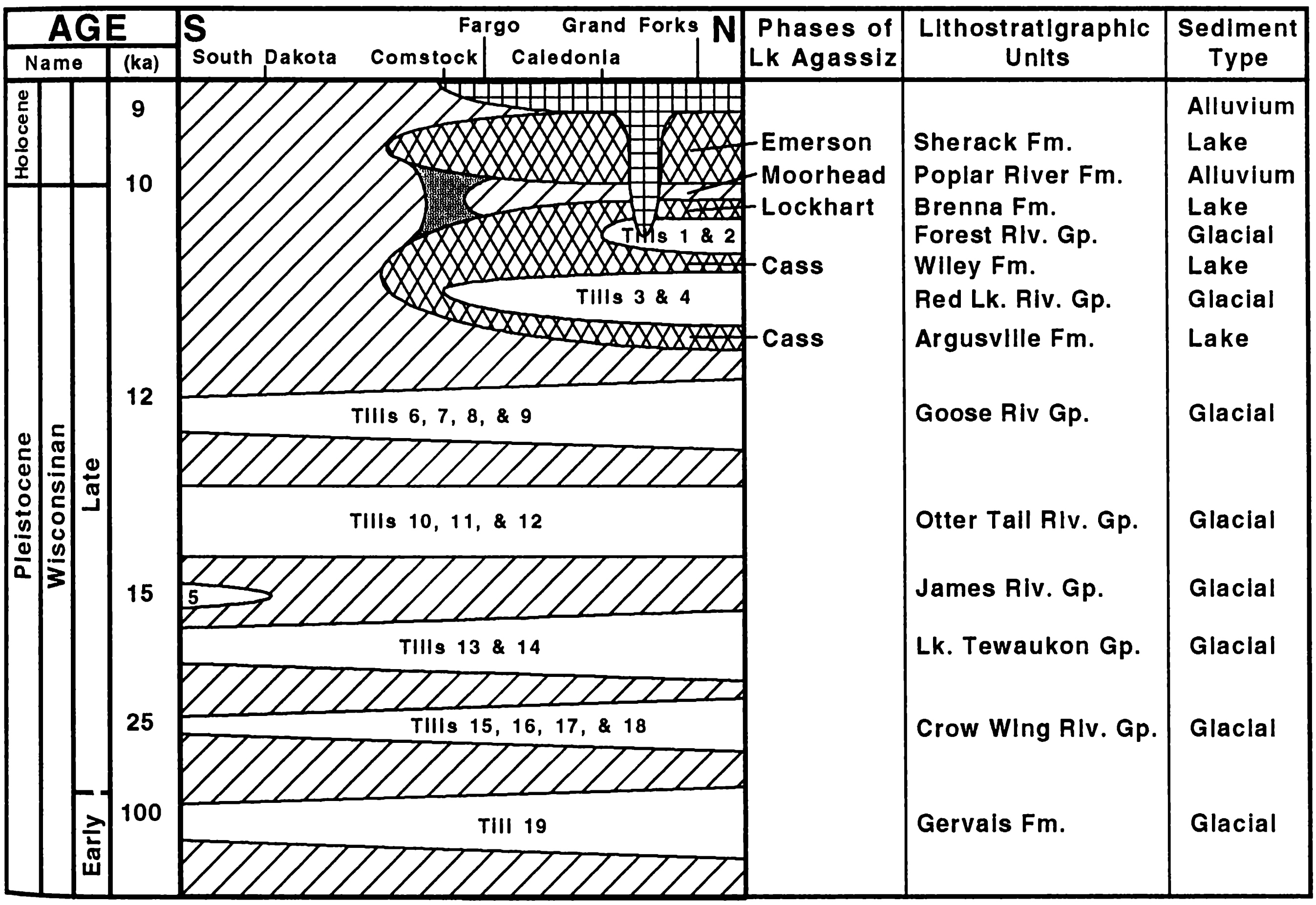


Figure 4. Time-distance diagram showing relative age and spacial relationship of lithostratigraphic units in the southern Lake Agassiz basin.

Glacial ice flowed south into the Lake Agassiz basin from the Laurentide ice sheet, which covered much of North America (Figure 2). The Laurentide ice was thicker to the north because glacial ice accumulated more rapidly in areas of heavy precipitation. The areas of thicker ice are called ice domes or centers. The ice in the domes flowed in response to the pressure of burial and gravity. The direction of movement was away from the ice domes. Ice lobes moved southward, away from the Keewatin and Labradoran ice domes, into North Dakota, Minnesota, and adjacent areas (Figure 3). The lobe that advanced into the southern part of the Lake Agassiz basin is called the Red River lobe. As ice lobes advanced, they reduced the volume of ice in the domes. The mass and velocity of individual ice lobes varied due to changing ice mass in the source area, mass wasting, topographic conditions, and bed conditions. As ice lobes advanced, they thinned; eventually they ceased to flow and retreated or stagnated in place. Multiple advances of glaciers created the complex network of moraines and outwash deposits found in North Dakota and Minnesota today.

Recent geologic investigations suggest that at least seven glaciers advanced into the basin during the last 100 thousand years (Ka) (Figure 4). Each of the ice lobes that advanced into the Lake Agassiz basin blocked the preexisting northerly drainage system (Figure 5). This resulted in the flooding of the basin and the formation of a proglacial lake. Most evidence of these lakes was destroyed by subsequent glaciations; only late Wisconsinan and Holocene sediments preserve a detailed history. There is, however, evidence for two lakes in the basin prior to Lake Agassiz. Lake sediment was recovered from two test wells drilled by the Minnesota Geological Survey (3). The recovered lake sediment is associated with the Crow Wing River Group (about 25 ka) and the Goose River Group (about 13 ka) (Figure 4).

Lake Agassiz was very large (Figure 6). It is estimated to have had a total inundated area of more than 350,000 mi^2 (about 900,000 km^2), although the lake never covered all this area at any one time (8). The size of the lake was controlled by the availability and elevation of outlets and the position of the ice front. It is difficult to say exactly what the outlet elevations were because bedrock has rebounded since the glacier melted, but the eastern outlets in Ontario were lower in elevation than the southern outlet near Browns Valley, Minnesota. The elevation of the southern outlet also changed as soft sediment was eroded by the water flowing through the outlet. Eventually River Warren, the outlet stream, eroded down to more resistant Precambrian bedrock, and stable lake levels were achieved. Well-defined beaches formed whenever the ice position and outlet elevation remained constant for an extended period of time. As the ice front retreated beyond the eastern outlets, the southern part of Lake Agassiz drained, and rivers reestablished their northward courses. The lake floor dried and was colonized by flora and fauna.

The presence of ice also diverted the preexisting tributary stream systems south into Lake Agassiz and to the southern outlet. In this way, Glacial River Warren captured all the drainage from the Rocky Mountains east to the Red River Valley. Ice-marginal streams carried a considerable discharge and created large spillways. Evidence exists for ice-marginal flow west of the Red River lobe, when it stood near Halstad, Minnesota (Figure 7a). The Elk Valley delta was deposited by the diverted Pembina River as it flowed along the

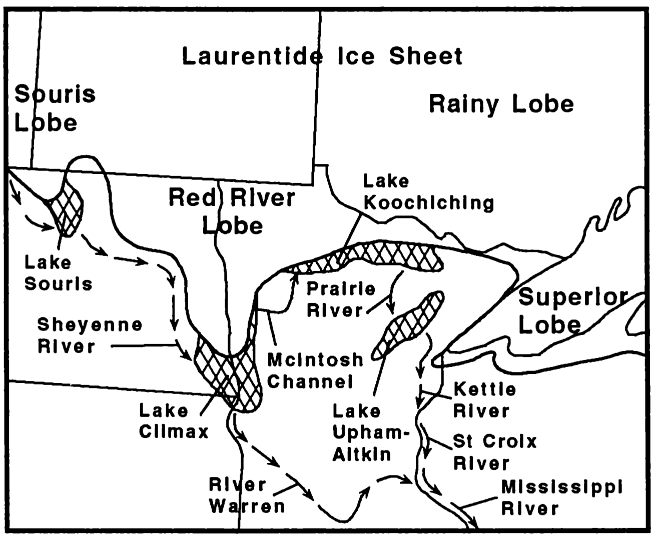


Figure 5. The Red River lobe at the Comstock ice-marginal position (about 11.5 Ka). Also shown are the early Lakes Climax and Kochiching. Modified from Clayton, 1983a.

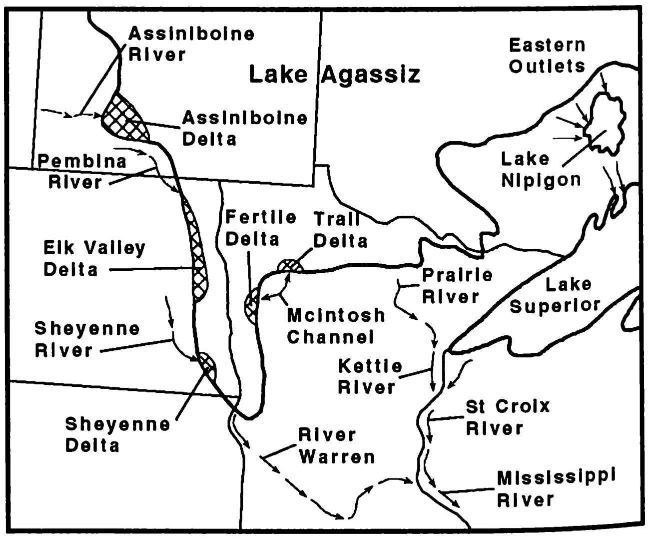


Figure 6. Maximum extent of Lake Agassiz and regional place names.

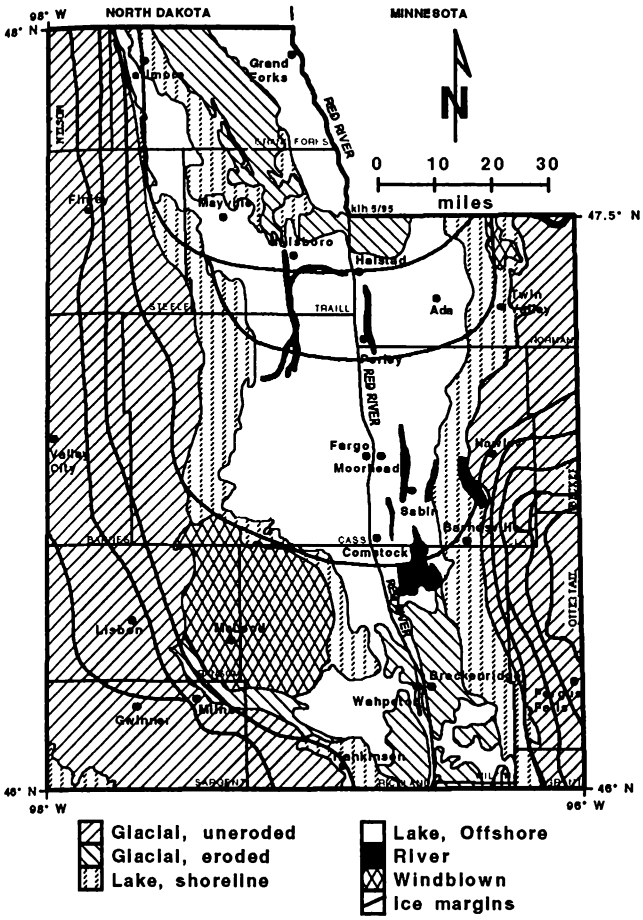


Figure 7a. Generalized surficial sediments in the southern part of the Lake Agassiz basin.

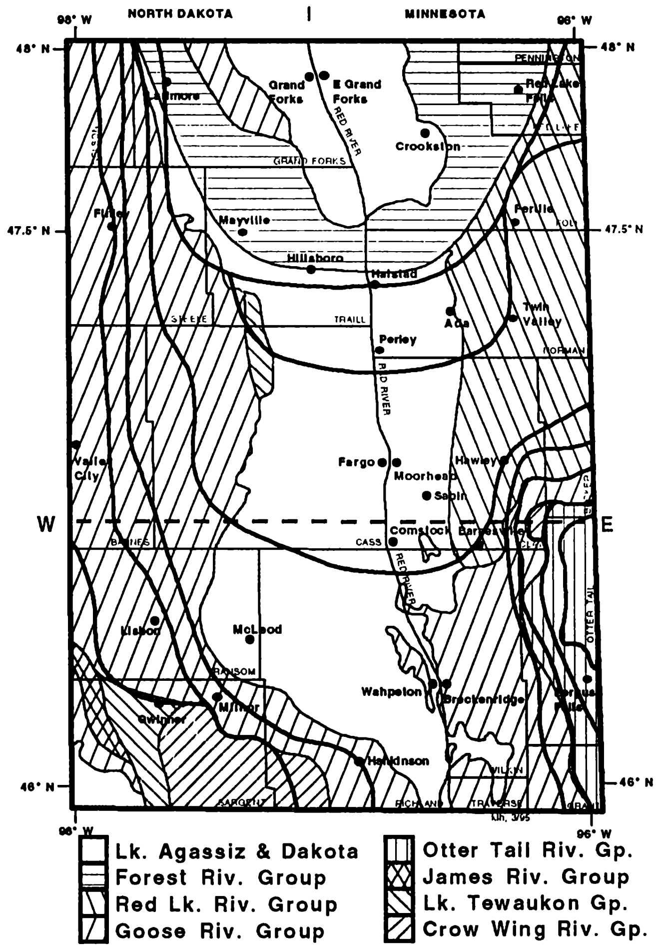


Figure 7b. Generalized lithostratigraphic map of the southern part of the Lake Agassiz basin. Cross section W-E is shown in Figure 8.

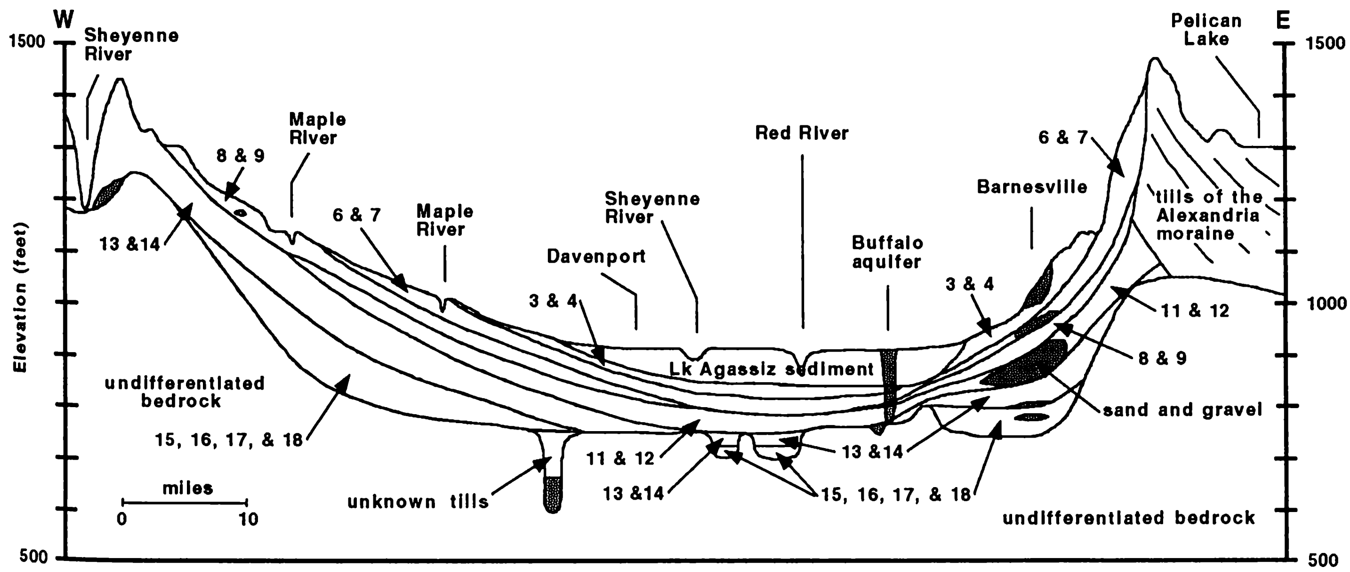


Figure 8. West-east cross section at 46.7° N latitude (see Fig. 7b); numbered lithostratigraphic units are identified in Figure 4: vertical exaggeration is about 190.

western ice margin into the southern part of Lake Agassiz (Figure 6). Similar conditions existed on the east side of the Red River lobe. The advancing Red River lobe split the Lake Agassiz basin into a northern lake (Lake Koochiching) and a southern lake (Lake Climax) (Figure 5). As water levels in the lakes fluctuated, water flowed back and forth between the two lakes through the McIntosh channel, forming the Fertile delta to the west and the Trail delta to the north (Figure 6) (9).

Holocene. The Holocene Epoch is the interglacial period in which we now live. The beginning of the Holocene is arbitrarily set at 10 Ka. At that time there was still glacial ice in the region, including the glacier that dammed the last phase of Lake Agassiz.

After Lake Agassiz drained, modern rivers reestablished their drainage systems. The Red River of the North and its tributaries are young rivers that flow within narrow valleys; they have not had time to form extensive flood plains. Large areas of the Lake Agassiz plain are covered by river overbank and overland flow sediment deposited during Holocene floods. Modern overbank sediments are found in the same areas, but are much less extensive.

Holocene windblown deposits are common on the deltas of Lake Agassiz (Figure 6). Since these deposits are not usually farmed, they are commonly set aside as wildlife management areas and natural areas. The Fertile dunes and the sand hills of the Sheyenne delta are well-known recreational areas located on Lake Agassiz deltas.

Glacial Sediment and Landforms

Sediment characteristics, landforms, and stratigraphy are the tools used to study the history and sequence of glacial events. The footprint of a glacier is the sediment and landforms that it leaves behind. Multiple glacial events in an area result in multiple footprints, one on top of the other.

The type of sediment deposited by a glacier is determined by the bed material in the glacier's flow path (Figures 1 and 2). Glacial sediment is a mixture of sand, silt, clay, cobbles, and boulders. Sediment deposited by ice streams following different flow paths can be distinguished using sediment texture and lithology. The lithostratigraphic map and cross sections (Figures 7b and 8) show spatial relationships between stratigraphic units identified in the basin (3).

Landforms in the Lake Agassiz basin are subtle because they have been wave-washed (smoothed) and obscured by lake sediment. However, beach ridges, ice-drag marks, compaction ridges, ice-marginal positions, and tunnel valleys are identifiable (Figure 7a). Beach ridges (Campbell, Herman, etc.) formed along the shoreline every time there was a stable lake level. Ice-drag marks formed when icebergs entered shallow water and dragged across the bottom of the lake. Compaction ridges formed when lake sediment settled around coarse-grained river channel sediment. Ice-marginal positions are marked by moraines, or belts of hummocky topography, which formed when the margin of a glacier remained in one position for an extended time during retreat. Tunnel valleys formed when subglacial meltwater episodically drained from beneath a glacier.

Ice margins are particularly interesting, since they have stratigraphic significance. The best example of a wave-washed end moraine is the Edinburg moraine, which marks a stable position of the Red River lobe near Halstad, Minnesota. This glacier deposited the tills of the Forest River Group (3) (Figures 4 and 7b). A change in the nature of the surface sediments, from clayey lake sediment to clayey glacial sediment, is the only indication of its location. Outside the lake plain, in Grand Forks and Walsh Counties of North Dakota, the Edinburg moraine exhibits high-relief collapse topography more characteristic of a moraine.

Two other ice-marginal positions are interpreted to be present in the southern part of the Lake Agassiz basin. These ice margins cross the Red River south of Perley in Norman County, Minnesota, and south of Comstock in Clay County, Minnesota (Figures 7a and b). They represent stable positions of the retreating Red River lobe, and mark the southern boundaries of the Upper Red Lake Falls Formation (Perley ice-marginal position) and the Lower Red Lake Falls Formation (Comstock ice-marginal position) (3). Compaction ridges oriented north-south are present at both of these ice margins and have been interpreted to be sediment-filled tunnel valleys (Figure 7a).

CONCLUSION

The Lake Agassiz basin has had a long and complex history (10,11,12). An understanding of the geologic history of the Lake Agassiz basin provides a historical context in which to place modern regional flooding.

Bedrock topography and hardness controlled the path followed by the Red River lobe. Each glacial event eroded soft bedrock more than resistant rock. Continued differential erosion of the soft Cretaceous shale created a trough (or channel) in which ice lobes flowed and lakes ponded. Lakes formed south of the ice front as each glacier advanced and retreated. There is evidence for at least four proglacial lakes in the basin during the past 25 Ka; the last two lakes were phases of Lake Agassiz.

The Red River Valley is technically not the valley of the Red River, but rather the floor of a glacial lake. It is an area of relatively low elevations and low relief, and is susceptible to widespread flooding. The low relief, low gradient, and the presence of impermeable lake sediment combine to contribute to the modern potential for flooding.

REFERENCES

1. Harris, K. L. (1987) Surface geology of the Sheyenne River map area. North Dakota Geological Survey Atlas Series AS-15-A1, scale 1:250,000.
2. Harris, K. L., and Luther, M. L. (1991) Surface geology of the Goose River map area. North Dakota Geological Survey Atlas Series AS-14-A1, scale 1:250,000.
3. Harris, K. L., project manager (1995) Regional hydrogeologic assessment: Quaternary geology-southern Red River Valley, Minnesota. Minnesota Geological Survey Regional Hydrogeological Assessment Series RHA-3, Part A, 2 plates, scales 1:200,000 and 1:750,000.
4. Goldich, S. S. (1972) Geochronology in Minnesota, *in* P. K. Sims, and G. B. Morey (eds.) Geology of Minnesota: A centennial volume. Minnesota Geological Survey, pp 27-37.
5. Moore, W. L. (1979) A preliminary report on the Red River Valley drilling project, eastern North, Dakota and northwestern Minnesota. U.S. Department of Energy Open-File Report GJBX-3(79), 292 pp.
6. Jirsa, M. A., Runkel, A. C., and Chandler, V. W. (1994) Bedrock geologic map of northwestern Minnesota. Minnesota Geological Survey Miscellaneous Map Series M-80, scale 1:250,000.
7. Morey, G. B. (1993) Geologic map of Minnesota. Minnesota Geological Survey State Map Series S-19, scale 1:3,000,000.
8. Bluemle, J. P. (1991) The face of North Dakota. North Dakota Geological Survey Educational Series No. 21, 177 pp.
9. Clayton, L. (1983) Chronology of Lake Agassiz drainage to Lake Superior, *in* J. T. Teller and L. Clayton (eds.) *Glacial Lake Agassiz*. Geological Association of Canada Special Paper 26, pp 291-307.
10. Arndt, B. M. (1977) Stratigraphy of offshore sediment Lake Agassiz - North Dakota. North Dakota Geological Survey Report of Investigation No. 60, 58 pp.
11. Clayton, L., and Moran, S. R. (1982) Chronology of Late Wisconsinan glaciation in Middle North America. Quaternary Science Reviews, vol. 1, pp 55-82.
12. Fenton, M. M., Moran, S. R., Teller J. T., and Clayton, L. (1983) Quaternary stratigraphy and history in the southern part of the Lake Agassiz basin, *in* J. T. Teller and L. Clayton (eds.) *Glacial Lake Agassiz*. Geological Association of Canada Special Paper 26, pp 49-74.

ARCHAEOLOGY AND FLOOD DEPOSITS AT THE FORKS, WINNIPEG, MANITOBA, CANADA

Sid Kroker
Quaternary Consultants Ltd.
130 Fort Street, Winnipeg, Manitoba, Canada R3C 1C7

PREAMBLE

Archaeology, while concerned primarily with past human behaviour as exemplified in the preserved material culture, must also be cognizant of the environment within which the people lived. Changes in the environment, either short-term or long-term, will result in changes of the adaptive strategies employed for survival. Floods can produce both long-term and short-term effects upon the topography, flora, and fauna.

Topographical changes such as the cutting of new river channels may create oxbow lakes, which will increase harvest opportunities for waterfowl and edible plants such as cattail (*Typha*) and arrowhead (*Sagittaria*). Conversely, these changes may eliminate spawning localities, thereby reducing or changing fishing strategies in a specific region.

The effect of floods upon the vegetation in the riverine gallery forest will vary with the species and the depth of sediment deposition. Thin deposits of silts and clays may have minimal effect beyond enriching the soil. Thick deposits may suffocate some plants and cause short-term diminishment of some species until they reestablish themselves. This could cause modifications of the seasonal round if the species are important for food or medicine. Floral changes can cause displacement of faunal resources, which may also be in short supply locally due to decimation or relocation directly attributable to the flood.

For the past decade, numerous archaeological projects have been conducted at the junction of the Red and Assiniboine Rivers in Winnipeg. These projects have provided a window into the types of riverine sedimentation and raised the hope of being able to develop a chronological sequence of flood events. The standard textbook example of sedimentary stratification depicts layers of different soils; this layer-cake pattern does occur at The Forks (Figure 1). However, in a flood zone situation, this type of soil profile is actually an anomaly. In reality, over distances greater than 5 m (16.4 ft), the pattern of soil layering is more likely to resemble a marble cake. This is caused by irregular deposition and erosion during each high-water episode. Ice jams and deadfall jams can divert flow, causing erosion to the sides and deposition in the dead water behind. Uprooted trees leave large hollows, which may either be filled by sediment or enlarged and deepened by swirling water. The maelstrom of activity below the surface of the flood waters results in an uneven pattern of sedimentation different\sizes of particles (sand, silt, or clay) are deposited in adjacent areas, and the thickness of the deposition varies. Excavation of long, continuous trenches during archaeological impact assessments has provided an opportunity to examine the continuity of strata over distance. It is not uncommon for a stratum, even a fairly thick one (10 to 15 cm; 0.3 - 0.5 ft), to pinch out and reappear 10 or 15 m (32.8 - 49.2 ft) away. Thus, interrelating disjunct strata over intervening distances, sometimes as little as 5 m (16.4 ft), is a major problem in determining synchroneity of cultural horizons.

A second problem occurs with the relocation of cultural material by moving water. Relatively moderate flows can lift and move charcoal and lighter bone, which become incorporated into the sediment load and redeposited at a new location. These flood-churned strata do contain archaeological data, but they have become separated from the primary locus of deposition, thereby minimizing any analytical value of recoveries from these strata. Due to the vagaries of water flow, the primary occupation site could be located in any direction at distances greater than twenty metres.

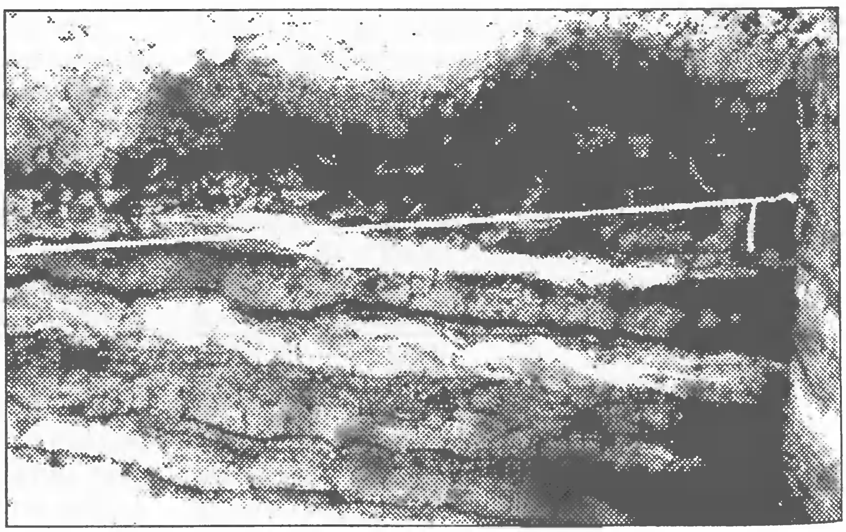


Figure 1. Stratigraphic sequence of horizontal layers.

CHRONOLOGICAL CORRELATIONS

Even when dealing with historic data, where the dates of the floods are known, it is often impossible to correlate the various strata with specific flood events. At Winnipeg, four major floods have been recorded during the 19th century 1826, 1852, 1861, and 1882. Only some of the strata recorded in the profile at the excavations of the North West Company post of Fort Gibraltar I can be definitely linked to specific events (1). This profile (Figure 2) has definite bounding limits. The fort was destroyed and burned by the Hudson s Bay Company in 1816, resulting in a thick layer of partially charred timber and fired chinking (the clay which had served as insullation between the logs). The Northern Pacific and Manitoba Railroad Company constructed a roundhouse immediately adjacent in 1888.

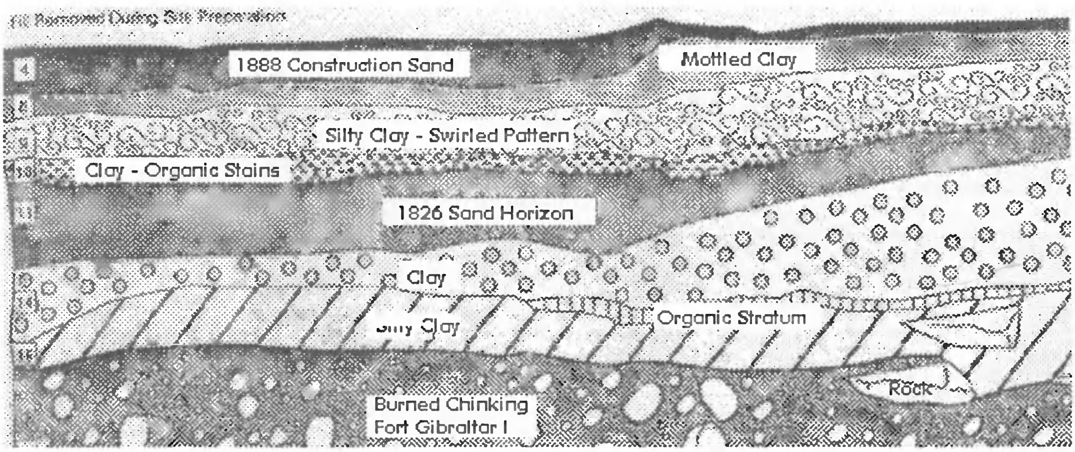


Figure 2. Soil profile at Fort Gibralter I.

Between the chinking layer, dating to 1816, and the construction sand layer of 1888, there are seven distinct strata. Layer 10, an organic-stained clay, contains manure and other deposits related to the Hudson s Bay Company Experimental Farm, which was in operation from 1836 to 1848. Therefore, this layer had to have been deposited prior to the 1852 flood, leaving four strata below it that derive from the 36-year period between the destruction of the fort and 1852. The 1826 flood, the most massive recorded at Winnipeg, would be responsible for the deposition of Layer 11, a sand stratum which varies in depth from 1 to 15 cm (0.3 - 0.5 ft), depending upon location. The organic clay horizon could be the final stage of deposition by the 1826 flood, as the waters were stagnant or receding, with resurgent vegetation providing the organic component. However, the three strata below the sand horizon present interpretive problems no floods, or even high-water episodes, are recorded in the historical archives. The lowest silty clay stratum had to be deposited after 1816, with sufficient time for an organic stratum to form above it prior to the deposition of the clay horizon. Similar interpretive problems occur with the upper strata: three floods (1852, 1861, and 1882) and only two layers. Artifacts recovered from the uppermost mottled clay horizon are ambiguous. Some, like shotgun cartridge shells, are relatively late, while others such as ceramic sherds and clay pipe fragments have temporal ranges from the 1840s to the early 1900s. The mottling derives from organic components in the soil matrix and indicates the presence of a humic horizon with a degree of vegetative cover. It is unlikely, therefore, that this horizon derives from the 1882 flood, as there would be insufficient time (6 years) to form an incipient A Horizon. Tentatively, the stratum is correlated with the 1861 flood and the underlying layer of silty clay, which has a swirled pattern, is attributed to the 1852 flood. Even when the events are known, as shown above, correlation of specific sediment strata with corresponding floods is often tentative.

The situation becomes even more tenuous when the events can be chronologically placed only through stratigraphic position, radiocarbon dates, and/or culturally diagnostic artifacts. Two examples will be presented. A massive sand horizon, predating the advent of Europeans to the area, occurs at several locations at The Forks. This horizon can range up to 1 m (3.3 ft) thick, indicating a very severe flood. By comparison, the deepest sand deposition attributable to the 1826 flood is 15 cm (0.5 ft). A section adjacent to the natural levee of the Assiniboine River was exposed during construction activity (Figure 3). Incorporated in the lower

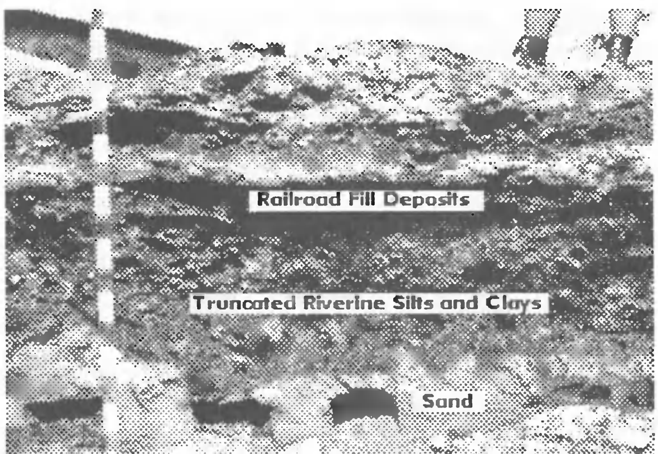


Figure 3. Sand stratum from the 750-Year flood.

portion of the stratum were the bones of a female bison (*Bison bison*) and foetal calf bones. The presence of the foetal bone indicates that the pregnant cow perished during the winter or spring of the major flood and was not reposited from another location. A radiocarbon date of 740 ±100 years B.P. was obtained from the bone (2), indicating that this massive flood occurred between 1100 and 1300 A.D. Pollen data indicate a major warming trend that appears to have climaxed at that time (3), correlating with the close of the Sub-Atlantic Period, as defined by Bryson, Baerreis and Wendland (4). The arid conditions would mean that soil in the catchment basin was more susceptible to erosion.

This flood stratum, while not firmly temporally placed, can provide limiting data for some cultural activities. The storage pit, depicted in Figure 4, was excavated down into the

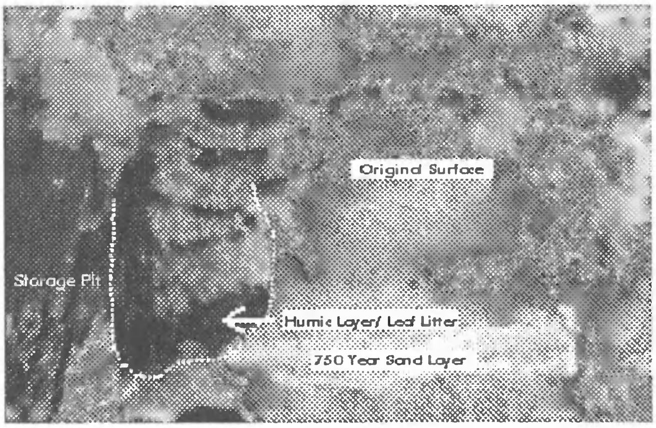


Figure 4. Storage pit - ca. 600 B.P.

top of the 750-Year-Flood sand stratum. The original surface at the time of the excavation appears to be a minimum of two depositional events after the sand layer. The pit appears to have been left open and accumulated leaf litter, which decayed into a humic deposit. A radiocarbon date would provide an upper limit for the activity. Unfortunately, the discovery occurred during a construction-monitoring project and the budget precluded obtaining a linear accelerator date on the organic material.

A major archaeological horizon, occurring at a depth of 3 m (9.8 ft) below the surface was dated at 2870 ±80 B.P. (5), 2850 ±90 B.P. (2, 6), and 2815 ±75 B.P. (6). Three distinct

Figure 5. Projectile points from the 3000-year old trade center and campsite.

types of projectile points (Figure 5) have been recovered from an extensive occupation site. The identification of these points as Hanna, Shield Archaic, and Pelican Lake (7) concur with the radiocarbon dates as the temporal ranges of each style of projectile point encompasses the dates for the site. The point styles are indicative of two different cultured groups from the prairie (Duncan/Hanna and Pelican Lake) and a boreal forest-adopted group meeting (Shield Archaic) and trading at the same locality. An adjacent portion of the site was interpreted as a bison-processing locality (8). Hearths and conglomerations of bison bone occurred at the same stratigraphic level–resting on a thick sand horizon that displayed considerable cross-bedding (Figure 6). The presence of this thick sand stratum represents either a massive flood similar to the 750-Year Flood or the cutting of the channel in which the Assiniboine River now flows.

The channel-cutting hypothesis differs from the current postulation that the Assiniboine River occupied its present channel approximately 1300 years ago (9). The presence of such massive quantities of sand, both above and below the cultural horizon, suggests that considerable sediment was being transported. Glacial till reaches the surface approximately 5 km (3.1 mi) upstream of The Forks along the Assiniboine, and this could be the source of these sand deposits. It is unlikely that this quantity of sand would be transported by the Red River, as the nearest sand source is many kilometers distant.

In summary, flood episodes provide both benefits and problems for interpretation of archaeological data. Sediment deposition can provide a layer of sediment over top of a horizon, thereby producing a sealed time capsule (Figure 7). Within that capsule are the tools and food remains of the people who occupied the site. Chemical and palynological analysis of the underlying soil can provide a picture of the contemporary environment in which the people undertook their activities: hunting, fishing, plant gathering, and tool manufacturing. An extraordinary example of a time capsule preserved by flood sediments occurs in the clay stratum below the 1826 flood sands at the Fort Gibraltar I site. Impressed into the clay are a series of prints cattle, horse, narrow-rimmed buggy wheels, and one moccasin-clad human foot (10). These prints (Figure 8) must have been made when the clay was wet and then dried or froze prior to the onset of the 1826 flood. The difference in textures between the clay and the overlying sands prevented melding of the sediments, and careful excavation exposed this scene of ephemeral activity, which has been preserved in plaster casts. It is tempting to visualize the scene as a frenetic rush from Fort Garry at the junction of the Red and Assiniboine Rivers as the waters began to rise. People on horseback, in buggies, and on foot, taking their belongings and driving their cattle toward higher ground, passed over this spot the afternoon before the flood. Overnight, the clay froze and the sand horizon was deposited as the first massive deluge slowed and spread over the

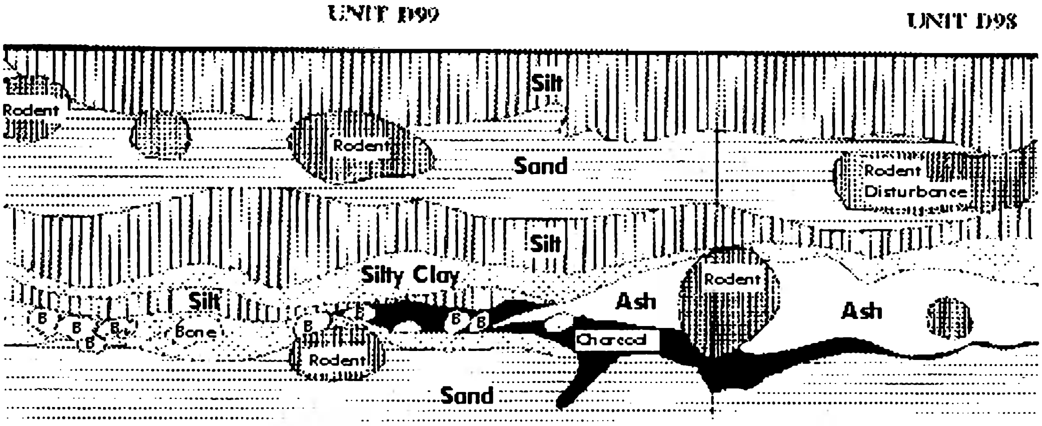
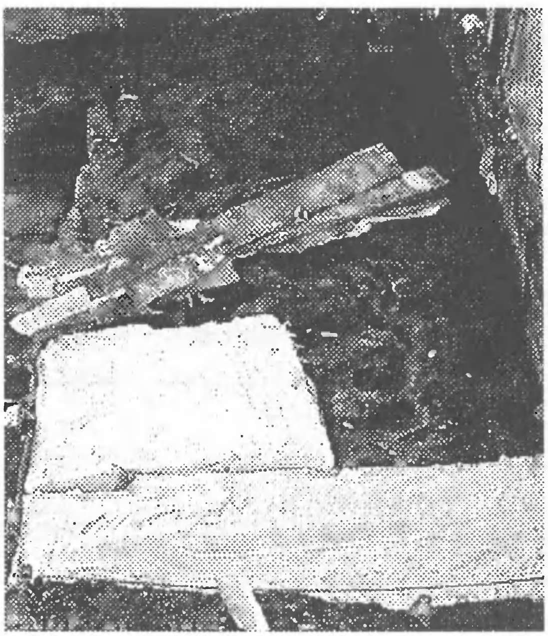


Figure 6. 3000-year old bison processing area.

Figure 7. Hearth truncated by flood sediments.



Figue 8. Plaster preservation of prints.

Winnipeg area. On the down side, the flood waters often erase or relocate cultural deposits, which means that discoveries are often free-floating in a temporal sense.

When archaeological activity began at The Forks, the archaeologists naively believed that Quaternary geologists and sedimentologists could provide a temporal chart within which the cultural manifestations could be easily placed. At the same time, those scientists believed that the culturally diagnostic artifacts deriving from archaeological sites would firmly date major depositional events. Both parties, now convinced that there are no easy answers to the chronology, work together to attempt to provide a useable framework. At some localities at The Forks, there are 10 m (33 ft) of riverine sediments resting on Glacial Lake Agassiz clay. Somewhere in those sediments, deposited after the lake drained 8500 years ago, is the "perfect profile" that has a representation of every flood event and enough organic material in the strata to provide radiocarbon dates for each and every event.

REFERENCES

1. Kroker, S., Greco, B. B., and Thomson, S. (1991) 1990 Investigations at Fort Gibraltar I: The Forks Public Archaeology Project. Canadian Parks Service, The Forks Renewal Corporation, Historic Resources Branch of Manitoba Culture, Heritage and Citizenship, Winnipeg.
2. Kroker, S., and Goundry, P. (1990) Archaeological monitoring of the Stage I Construction Program. The Forks Renewal Corporation, Winnipeg.
3. Bernabo, J. C. (1981) Quantitative estimates of temperature changes over the last 2700 years in Michigan based upon pollen data. Quaternary Research 15:143-159.
4. Bryson, R.A., Baerreis, D.A., and Wendland, W.M. (1970) The character of late-glacial and post-glacial climatic changes. In Pleistocene and Recent Environments of the Central Great Plains (Dort, W., and Jones, J.K. Jr., eds), pp 53-74. University of Kansas, Department of Geology, Special Publication 3.
5. Kroker, S. (1989) North Assiniboine node archaeological impact assessment. The Forks Renewal Corporation, Winnipeg.
6. Kroker, S., and Goundry, P. (1993) Archaeological monitoring and mitigation of the Assiniboine Riverfront Quay. The Forks Renewal Corporation, Winnipeg.
7. Kroker, S., and Goundry, P. (1994) Archaic occupations at The Forks. The Forks Public Archaeological Association, Inc., Winnipeg.
8. Quaternary Consultants Ltd. (1993) Archaeological mitigation of the Johnston Terminal Refurbishment Project. Marwest Management Canada Ltd., Winnipeg.
9. Rannie, W.F., Thorleifson, L.H., and Teller, J.T. (1989) Holocene evolution of the Assiniboine River paleochannels and Portage la Prairie alluvial fan. Canadian Journal of Earth Sciences, 26 pp 1834-1841.
10. Kroker, S., Greco, B. B., and Peach, K. (1992) 1991 Investigations at Fort Gibraltar I: The Forks Public Archaeology Project. The Forks Public Archaeological Association, Inc., Winnipeg.

FACTORS AFFECTING FLOODING IN THE RED RIVER VALLEY

John P. Bluemle
North Dakota Geological Survey, 600 East Boulevard Avenue, Bismarck, ND 58505-0840

INTRODUCTION

The cities of Grand Forks and East Grand Forks (North Dakota and Minnesota) suffered a devastating flood in April of 1997 that inundated 80% of the cities and forced almost total evacuation of the population (1). In the weeks and months following the flood, frustrated citizens and officials have charged that various agencies provided inaccurate forecasts of flood levels. Could the forecasts have been more accurate? Statements have also been made that the flood happened because not enough water is stored in wetlands or because farmers have illegally drained the land.

It has been charged that, despite the knowledge that total snowfall accumulation in the Red River drainage basin was at an all-time high (Fargo, 70 mi [113 km] upstream, had received the greatest snowfall in its recorded history - 115 in [2.92 m]) and despite reports that soil in the Red River Valley was saturated from heavy moisture the year before, the National Weather Service did not waver from its prediction that the river would reach a gage level of 49 ft (14.9 m) in Grand Forks, about the same as the 1979 flood, the flood of record in the area.

What are the factors affecting flooding in the Red River Valley? Is it possible to predict, with anything approaching certainty or accuracy, how serious a flood will occur in any given year? Or, perhaps, would it be as effective to simply visit with the old-timers in the county, who this year after walking through their fields following the seventh snowstorm, commented something to the effect: "Pretty wet out there. Never seen nothin' like it. It's gonna be a bad one" (1).

I believe there is a scientific approach to understanding the flooding problem (even though I cannot guarantee that it will be any more accurate than listening to the old-timers). Geologists at the North Dakota Geological Survey have identified a variety of constant and variable factors that affect or contribute to flooding in the Red River Valley (2).

DISCUSSION

Constant Factors

Direction of River Flow. The northerly flow of the Red River can affect the timing of the thaw. If the snowmelt occurs in the south before melting has begun in the north, the water can flow from a thawed to a frozen area, causing ice jams and other problems.

Drainage Ditches. Even though they are constructed features, once built, drainage ditches have a constant effect year after year. Drainage ditches result in faster and more complete runoff to the river. Water once stored on the flatlands bordering the river is now poured into the river during the spring thaw.

More than 28,000 mi (45,060 km) of legal, human-made ditches have been constructed in the Red River Valley of North Dakota and Minnesota. The main effect of the ditches, apart from the fact that they help to drain the farmland (as intended), is that they move water from the land to the river much more quickly than do the natural tributaries. In short, they result in water arriving at the river sooner than it otherwise would.

Rural Road System. The rural road system plays an important role in determining the manner in which water runs off the land. In many places where culverts are too small to handle a large flow, water becomes dammed against the roads. When the snow cover melts, water pours over the land, washing out bridges and stripping the gravel off the roads.

The Gradient of the Red River. The gradient (slope) of the Red River is exceptionally flat, a combined result of the deposition of sediment on the floor of glacial Lake Agassiz and of glacial rebound, which has differentially raised northern areas more than it has southern areas.

The modern gradient on the Red River is about 16 in/mi (25 cm/km) downstream from Wahpeton; 11 in/mi (17 cm/km) downstream from Fargo; 7 in/mi (11 cm/km) downstream from Grand Forks; about 4 in/mi (6.3 cm/km) downstream from Pembina. At Winnipeg the gradient is 3 in/mi (4.7 cm/km), and it is even less north of there. River gradient is an important factor because it controls the flow velocity. A low gradient causes the river to drain very slowly.

Flow Velocity. The velocity of flowing water is approximately proportional to the square root of the gradient (Manning's Equation). For example, at Fargo, the river gradient is about 0.9 ft/mi (0.17 m/km). The gradient along a drainage ditch arriving at Fargo from the west is about 3.6 ft/mi (0.68 m/km), four times the gradient on the Red River. Since the square root of four is two, drainage ditches entering the Red River in the Fargo area deliver water to the river about twice as fast as the river can carry it away without flooding.

Natural tributaries, flowing bankfull, but not flooding, deliver only sufficient water to the Red River to cause it to flow bankfull itself. That is, the gradients of the natural tributaries are more or less in step with the Red River gradient and with what the channel can carry without flooding.

The very low gradients along the Red River seriously restrict the speed at which water can flow in the river (2). We have observed in our studies of the floods along the Red River in past years, particularly those in 1975 and 1979, that the river spreads out greatly a short distance north of Grand Forks. In the Manvel, North Dakota-Oslo, Minnesota, area, the floodwater may inundate an area 4 or 5 times as wide as it does at Grand Forks. Part of this difference was due to efforts (successful in 1979 but not in 1997) to contain the river as it flowed through Grand Forks-East Grand Forks. The main reason for the great spreading of the floodwater north of the city is that the lower gradient in the Oslo area does not allow the water to drain away as fast there. As a result, the floodwater pools up when it is delivered to the area faster than it can flow away.

Urban Areas. The expansion of urban areas has resulted in a decrease in the area available for infiltration. The construction of streets and sewers increases the speed with which an area can drain.

Bridges, Dikes, and Other Impeding Structures. These may contribute to impeding flow on the river, thereby contributing to flooding.

Variable Factors

Timing of the Thaw. Late thaws (late March or April) are generally more rapid, result in quicker runoff, and are more likely to arrive over the whole Red River drainage basin at about the same time. Early thaws (February or early March) commonly affect only the southern end of the basin.

Winter Snow Accumulation and Precipitation During the Thaw. The amount of water available is the basic ingredient of a flood.

Thaw Rate and Other Weather Conditions. The faster the thaw takes place once it starts, the more quickly water gets to the river. Cool, freezing nights help to slow the melt. Cloudy days also help to "pace" the melt. Windy weather can evaporate some of the water (or it may bring warm air to the area). Early March thaws usually are slower than those that come in April.

Timing of the River Crests on the Red and Red Lake Rivers and Other Tributaries. The Red Lake River will commonly provide up to 40% of the total flow at Grand Forks-East Grand Forks during the spring flood. If maximum flow on the Red and Red Lake Rivers occurs at the same time at the confluence of the two rivers, the problem is compounded. If the crests are spaced apart, flooding may be less severe.

Severity of the Winter. The severity of the winter cold affects the amount of snow remaining when the spring thaw arrives. The Fargo-Grand Forks area can sometimes have 100 consecutive days during the winter with few, if any, thawing days. Snow that fell in November can still be on the ground in April. The average depth of frost penetration in the Grand Forks area is 4.5 ft (1.4 m), but it can be as deep as 7 ft (2.1 m) if the ground is bare.

Condition of the Soil. If heavy rainfall occurs before freeze-up in the fall of the previous year, the soil within the drainage basin will be saturated with moisture when it freezes. It will therefore be able to absorb very little additional moisture when the spring thaw begins. Thus, a wet fall sets the stage for a flood by increasing the amount of winter and spring runoff that must be carried by the rivers.

The soil can also tend to seal itself if the water flows over it rapidly. That is, the clay-rich soil particles swell and initially form a seal when water flows over an area, but the soil particles tend to dissociate if water stands on an area, allowing water to infiltrate.

Frozen Soil. Water cannot penetrate deeply frozen soil and subsoil. Generally, the colder the winter, the greater the depth of frost penetration into the soil and the slower the ground will thaw in the spring. Runoff is thus increased. However, a heavy snow cover insulates the ground from deep freezing.

Ice Thickness. During unusually cold winters, especially if the early winter snowfall is light, a greater-than-average thickness of ice forms on the rivers. Thicker ice remains on the river longer in the spring. Until the ice clears from the river, the flow of floodwater is impeded and the threat of ice jamming exists.

Sedimentation. The turbidity of the Red River is caused by fine-grained sediment (silt and clay) carried in the water. Measurements made during the summers of 1965 and 1966 showed that the water in the Red River at Grand Forks-East Grand Forks contained from 80 to 230 parts per million of suspended sediment. During a typical summer day, more than 1620 tons (1470 metric tons) of suspended sediment pass through Grand Forks-East Grand Forks. During peak flows, when the river reaches levels of more than 45 ft (13.7 m), more than 34,000 tons (30,844 metric tons) of sediment can pass through the two cities in a day.

The unusually large amount of suspended sediment in the Red River is eroded from the clay and silt layers of lake sediment of the valley. In addition to being eroded, sediment is also deposited on the river floor during times of low flow, on the levees and lawns in Grand Forks and East Grand Forks during floods. Deposition of sediment on the river floor can contribute to decreasing the capacity of the channel to carry water.

A worst-case scenario, leading to a serious flood, would be a combination of the following:

- a wet fall
- a cold winter
- heavy winter snow accumulation
- a late, cool, wet spring followed by sudden warming
- widespread, heavy, warm rainfall during the thawing period

Probably the only one of these factors that alone can cause a serious flood is the amount of snow that has to melt and, possibly, the amount of spring rainfall. Beyond that, it is the interplay of several or all of these constant and variable factors that usually determines how serious the spring flood on the Red River will be.

History of Flooding in Grand Forks-East Grand Forks

Official recording of flood levels in Grand Forks-East Grand Forks began in 1882. Between 1882 and 1950, the cities had one severe flood approximately every 6 years (for this purpose, a "severe" flood in Grand Forks-East Grand Forks is defined as one that exceeds a gage level of 40 ft [12.2 m]). Since 1950, Grand Forks has had one severe flood about every 3 years.

Although official records are not available prior to 1882, eyewitness accounts indicate that between 1800 and 1855, the Red River flooded perhaps a half dozen times at levels estimated at more than 50 ft (15.2 m) in the Grand Forks-East Grand Forks area (2, 3, 4). All of these floods are poorly documented, but they occurred at a time when essentially nothing had been done to alter the environment.

We know that the climate in the Red River Valley has changed several times since the end of the glacial epoch. Available geologic information suggests that the late 19th century and the first half of the 20th century were drier than "average" conditions (conditions that were typical of the last couple of thousand years). The Red River Valley was settled during the last half of the 1800s and in the early 1900s (4). That settlement period coincides with the dry period - the 90 years prior to 1950 (5). For this reason, people have lived their entire lives in the Red River Valley knowing no other conditions than the dry ones, so they tend to think that this is the way it has always been and always will be. This is not necessarily so, and we need to consider the possibility that the "normal" situation is one in which severe flooding is a common occurrence, not just a fluke happening.

CONCLUSION

Flooding cannot be prevented. Some dikes will inevitably fail because we expect too much of them. Dikes inherently conflict with natural river processes, although they may serve a definite purpose and be absolutely necessary. Our current and traditional methods of flood control have locked us into a self-defeating mind-set: we use dams, dikes, and other structures to reduce the frequency of destructive floods (3). As a result, moderately damaging floods occur much less often, reinforcing the expectation that we are safe from all floods. Dams and dikes lull us into thinking we can build safely on the floodplain. When catastrophic flooding does occur, as it inevitably will, and did in April, 1997, in Grand Forks-East Grand Forks, our typical response is to build more flood control structures. These structures cannot prevent all flooding, but they sometimes have the unfortunate effect of stimulating even more development of the floodplain, creating the stage for future flooding disasters. Ideally, I think local governments should discourage people from building on the floodplain in the first place (1, 2) (more easily said than done).

Most current flood control strategies incorporate misunderstandings of the concept of a 100-year or 500-year flood. Too many people have the notion that such a level of catastrophic flooding is likely to occur only once in a century or once in five centuries. Not nearly enough historical information is available to make that kind of a call. Rather, we should examine the geologic record and use that information to make a realistic appraisal of the potential for flooding and what can be done to deal with it.

Not only in the Red River Valley, but throughout the United States, floodplain zoning laws establish a "line" in the floodplain beyond which flood waters are not expected to extend for a period of 100 or 500 years (or some other interval) (6, 7, 8). Then (if we adhere to our zoning laws at all), we say it's all right to build up to the floodplain line, but no farther. There is no geologic or geomorphic reason to draw a line across a floodplain and expect that the water will not cross it at some time, if not in our lifetimes, then in our grandchildrens'.

Those people who have felt a need to assign "blame" for the 1997 flood disaster in the Red River Valley and the ongoing 1990s flood at Devils Lake need to realize that the flood was not "caused" by wetlands drainage or by agricultural practices or by any single one of the constant or variable factors noted in this paper. Floods occur most frequently during cycles of increased precipitation, and it was the amount of precipitation in the months leading up to the flood that caused the disaster at Grand Forks-East Grand Forks (9, 10). If we hope to understand and deal effectively with floods, we need to be aware of all of the geologic processes that affect flooding.

Floods are natural events (9, 10). There will always be floods. The Red River flooded long before any land was drained, before any land was farmed. Similarly, Devils Lake has overflowed to the Sheyenne River at least a half dozen times since it formed 10,000 years ago, and it has dried up completely several times. Neither of these events was caused by human intervention. Floods occur when precipitation exceeds the ability of the drainage to carry away the resulting runoff. Damage occurs when people and their structures get in the way of the flooding rivers or lakes.

REFERENCES

1. Glassheim, E. (1997) Fear and loathing in North Dakota. Natural Hazards Observer, 21, (6), pp 1-4.
2. Harrison, S. S., and Bluemle, J. P. (1980) Flooding in the Grand Forks-East Grand Forks area. North Dakota Geological Survey Educational Series 12, 66 pp.
3. [No author] (1997) Lawmakers get a lesson on floods and flood plains. Geotimes, June, pp 10-11.
4. Robinson, E. G. (1966) History of North Dakota. University of Nebraska Press, Lincoln, 599 pp.
5. Jensen, R. E. (1974) Climate of North Dakota. North Dakota National Weather Service, North Dakota State University, Fargo, North Dakota, 48 pp.
6. Dalrymple, T. (1960) Flood frequency analysis. U.S. Geological Survey Water Supply Paper 1543-A, 80 pp.
7. Murphy, F. C. (1958) Regulating flood-plain development. University of Chicago, Department of Geography Research Paper No. 56.
8. Federal Emergency Mitigation Agency (1997) Framework for federal action to help build a healthy recovery and safer future in Minnesota, North Dakota, and South Dakota, 36 pp.
9. Bluemle, J. P. (1997) Why the flood? A long wet cycle. Grand Forks Herald, May 27.
10. Bluemle, J. P. (1997) From the State Geologist. North Dakota Geological Survey Newsletter, 24 (2) pp. 1-2.

UNET UNSTEADY FLOW MODELS FOR THE RED RIVER OF THE NORTH

Terry R. Zien
St. Paul District, U.S. Army Corps of Engineers
190 5th Street East, St. Paul, Minnesota 55101

INTRODUCTION

General

Minnesota and North Dakota properties adjacent to the Red River of the North are subject to frequent damaging inundation from minor and major flood events. Portions of the river have been hydraulically modeled using the steady-state water surface profile HEC-2 and the UNET unsteady flow network computer programs. The construction of agricultural levees between Grand Forks and Drayton, urban levees, and the flood of 1997 have necessitated the evaluation of levee height and alignment on downstream locations. It is important to determine how existing and proposed flood reduction measures will modify flow and stage hydrographs as they move through the basin. The UNET computer program allows comparison of the downstream effects of differing levee heights and alignments to be applied to upstream locations. Diversions can also be readily modeled.

The UNET computer application for the Mississippi River has been modified within the last year to work with automated data collection systems that receive information from basinwide gage networks via satellite on a real-time basis. The existing automated gage network in the Red River basin could be enhanced to provide a real-time model of the Red River main stem. The current input scheme for the agricultural levee evaluation between Grand Forks and Drayton would need to be modified and areal coverage expanded. Impacts of releases on main stem stages from reservoirs at Lake Traverse, Orwell, Baldhill, Red Lake, and Homme Dams could be evaluated.

Background. In June 1975, heavy rains occurred in the southern (upstream) portion of the Red River Basin. Agricultural interests in the northern (downstream) portion of the basin constructed miles of levees adjacent to the Red River of the North in anticipation of crop-damaging flows. The dikes were successful in preventing crop damage in a number of locations. The effectiveness of the levees promoted the formation of several local flood control organizations interested in the development of additional local flood control measures.

The states of Minnesota and North Dakota recognized that uncontrolled diking along the river could possibly have a serious impact on other protected and unprotected properties along the Red River. The Walsh County Water Resource District (WRD), Grand Forks WRD, and some of the landowners in those districts were also concerned about the levees. The states requested technical assistance from the St. Paul District Army Corps of Engineers in the evaluation of the impact of the agricultural levees on Red River flood stages. When this work was initiated, it was jointly decided by the St. Paul District Corps of Engineers, the Minnesota Department of Natural Resources, and the North Dakota State Water Commission to use a steady flow model because no practical unsteady flow model existed. The UNET computer program became available several years later.

The Corps of Engineer's computer program HEC-2, Water Surface Profiles, was used by the St. Paul District to determine the impact of the agricultural levees on Red River flood stages. The HEC-2 program is intended for the one-dimensional calculation of water surface profiles for steady or gradually varied flow in natural and constructed channels. The effects of obstructions such as bridges, culverts, weirs, road embankments, and levees can be evaluated with the program. The results of the District's application of HEC-2 to the Red River were provided to both states for their use in the regulation of dike construction adjacent to the river.

The hydraulic characteristics of the Red River are such that storage areas behind the many overbank levees and road grades begin to fill when the water surface in the river rises above these features and empty as the river stages fall. Water that builds up behind roads and levees is from a combination of overflow from the main channel and overland flow. The HEC-2 program does not allow for such detailed hydrologic simulation of overbank inflow-outflow relationships with flow and stage on the main channel of the river.

The HEC-2 program is not appropriate to use when the flow rapidly changes with time (unsteady flow), when flow can change direction, when backwater effects can develop, when hydrologic routing techniques may not be reliable (slopes less than 5 ft per mile [0.9 m/km]), and when duration of flooding is of interest (coupling of the flood routing and water surface elevation computations). These conditions applied to the Red River model study, and the UNET program was capable of effectively dealing with them.

The states, local interests, and the Corps recognized the limitations of the HEC-2 analyses and began to examine the dynamic one-dimensional flow capabilities of other existing hydrologic simulation computer programs. Applicable hydrologic programs were reviewed, and the UNET (Unsteady NETwork) computer program was selected to model the dynamic one-dimensional flow aspect of the Red River and selected tributaries. A discussion of the decision process was summarized by the St. Paul District Corps of Engineers (1). The objectives of the modeling effort were to improve the analysis of flood conditions for the Red River of the North Basin and to develop a planning tool to evaluate future levee alignment and elevation proposals.

A pilot UNET study was performed in 1990 by the U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC) for the Red River between Grand Forks and Drayton, North Dakota (2). This study concluded that the UNET program could be used to model the Red River of the North, but greater detail was needed in the definition of overbank storage areas and the tributaries.

The UNET Computer Program. UNET is a one-dimensional unsteady flow numerical model that can simulate complex dendritic and full-network (looped) channel systems. For subcritical flow, the division of flow depends on the stages of each of the receiving channels. These stages are a function of channel geometry and downstream backwater effects. A second basic element of a full-network problem is the combination of dendritic flow channels. This is simpler than divided flow computations, because the flow in each tributary is dependent only on the stage in the receiving stream. The full network, or fully looped system, is the most general problem. It includes flow bifurcations, multichannel junctions, storage areas, and other internal boundary conditions.

Another element of the full network model is storage areas which behave as lakes and can provide water to or divert water from a channel. This is a divided flow problem where the storage area water surface will control the volume of water transferred. Storage areas can be the upstream or downstream boundaries of a river reach. In addition, the river can overflow laterally into the storage areas over a gated spillway, weir, levee, roadway or railway embankment, through a culvert, or by a pumped diversion. In addition to storage areas, UNET has the ability to apply several different external and internal boundary conditions, including flow and stage hydrographs, gated and uncontrolled spillways, bridges, culverts, and levee systems.

The UNET program uses cross sections that are input in modified HEC-2 forewater format (upstream to downstream). Existing HEC-2 input files can be readily adapted to UNET format using the COED (3) text editor as described in the UNET user's manual. Boundary conditions, such as stage and discharge hydrographs, can be input from any existing HEC Data Storage System (HEC-DSS) database (4). HEC-DSS is advantageous because it eliminates the tabular input of hydrographs and creates an input file that can be used in a large number of different alternatives. Hydrographs and profiles that are computed by UNET are output to HEC-DSS for graphical display and comparison with observed data.

Interaction between the channel and the floodplain can make the analysis of the movement of a flood through a river valley a two-dimensional problem. When the river is rising, water disperses laterally from the channel, inundating the floodplain and filling the storage areas. As the depth increases, the valley begins to convey water downstream, generally along a shorter path than that of the main channel. When the river stage is falling, the water moves toward the channel from the overbank storage areas, supplementing the flow in the main channel. This two-dimensional problem can often be approximated as a one-dimensional system because the primary direction of flow is still downstream. The lateral flow can be modeled as a storage area that exchanges water with the main channel. Flow in the overbank can be approximated as flow through a separate channel. Each channel has its own continuity and momentum equations. The UNET program assumes that the water surface at each cross section normal to the direction of flow is horizontal, that the exchange of momentum between the channel and floodplain is negligible, and that flow is distributed according to conveyances in the channel and floodplain, respectively.

Solutions to the resulting one-dimensional equations of motion are approximated using a linearized implicit finite-difference scheme. A system of simultaneous equations results for a reach of river. Using simultaneous solutions of the equations allows information from the entire river reach to influence the solution at any one point. The theoretical basis for the UNET computer program can be found in the user's manual (5).

METHODS

Data Required

Data with Format Similar to HEC Programs. Channel cross sections, normal bridge data, and Manning's "n" values are in nearly the same format as HEC-2 data and can be adapted from existing HEC-2 input files and converted to UNET input as described in the UNET user's manual (5). A thorough evaluation of the existing cross section data is important, because UNET accounts for the conservation of mass (volume) throughout a routing reach. Consequently, off-channel storage must be represented in addition to conveyance.

The normal bridge procedure simply subtracts the frontal area of the embankments and bridge structure from the cross-sectional area. The wetted perimeter is also increased by the wetted length of the piers and the bridge structure, with a resulting reduction in conveyance. The normal bridge procedure is preferred when the embankments are low and greatly submerged and when the bridge is a relatively minor flow obstruction. These crossings are commonly called perched bridges (5).

Data with Format Different from HEC Programs. Several input data types differ in format or use from the HEC-2 input style or did not exist. The special bridge procedure models the bridge crossing as an interior boundary condition, which substitutes a family of free and submerged rating curves for the unsteady flow equations. The free flow rating function describes the stage-discharge relation for the structure if the submergence from tailwater is not a factor. The family of submerged flow rating curves relates the tailwater elevation and the flow to the head loss (swell head) generated upstream of the structure (5).

Culverts restrict the flow to a small opening through an embankment. The constriction generates head loss (swell head), which can be several feet for severe restrictions. The embankment may be overtopped and act as a weir during high flow. The UNET program models culverts by computing a set of free and submerged flow rating curves for a system of up to five parallel culverts and four overflow weirs at any given location (5). The culverts can be circular pipes, pipe arches, pipe ellipses, or box culverts. The program allows the user to choose from 57 combinations of shape, material, and entrance configuration. The Federal Highway Administration (FHWA) procedure for computing culvert discharge is used by UNET.

A storage area is a lakelike region that can provide water to or divert water from a channel. Storage areas are defined by an elevation-volume relationship and can be located at the termination of a stream reach, connected to a channel by a lateral spillway, or connected to each other. The connections can be defined as a family of rating curves using culverts and/or weirs. The latter method is especially useful in the Red River Basin, because it allows flow to occur in either direction across the connection.

Boundary Conditions

For a reach of river, there are *N* computational nodes that bound *N-1* finite difference cells. From these cells, *2N-2* finite difference equations can be developed. Two additional equations are needed because there are *2N* unknowns, change in flow and elevation for each node. These equations are provided by the boundary conditions for each reach, which are required at the upstream and downstream ends of the reach for subcritical flow. Boundary conditions are required only at the upstream end of the reach for supercritical flow. UNET solves only the unsteady flow equations for subcritical flow conditions (5).

A channel network is composed of a set of *M* individual reaches. Interior boundary equations are required to specify connections between reaches. Depending on the type of reach junction, continuity of flow or continuity of stage equations are used. UNET applies flow continuity to reaches upstream of flow splits and downstream of flow combinations. Only one boundary flow equation per junction is used. Stage continuity is applied for all other reaches such that a stage common to all stage boundary conditions is set at the junction of interest.

Upstream Boundary Conditions. Upstream boundary conditions are required at the upstream ends of all reaches that are not connected to other reaches or storage areas. An upstream boundary condition is applied as a flow hydrograph of discharge versus time. UNET uses the complete hydrographs for hydraulic routing, not single values as in HEC-2.

Downstream Boundary Conditions. Downstream boundary conditions are required at the downstream end of all reaches that are not connected to other reaches or storage areas. Four types of downstream conditions can be described as stage hydrographs, flow hydrographs, single-valued rating curves, and looped rating curves that are computed by UNET using a simplified form of the momentum equation and Manning's equation (5).

A stage hydrograph of water surface elevation versus time may be used as the downstream boundary condition if the stream flows into a backwater environment such as a lake or reservoir of known stage. A flow hydrograph may be used if recorded gage data are available and the model is being calibrated to a specific flood event. The single-valued rating curve is a monotonic function of stage and flow that can be used to accurately describe the stage-flow relationship of free outfalls such as waterfalls, spillways, weirs, or lock and dam operations. This boundary condition should be avoided for free-flowing streams, as errors can be introduced into the solution which can propagate far upstream of the downstream boundary location. Use of Manning's equation with a time-variable friction slope produces an approximation of the looped rating curve seen in natural rivers. This type of boundary condition has the advantage of being able to pass waves downstream, but should be used with the understanding that the approximation may not accurately reflect the true looped rating curve (5).

The UNET System of Programs

The components of the UNET system consist of five modules in addition to HEC-DSS. They are CSECT, RDSS, UNET, TABLE, and UNETMU. The program CSECT reads a geometry input file, denoted by a ".CS" extension, and converts cross section data into tables of elevation versus area, conveyance, and storage. It also tabulates interior boundary conditions and resolves network connections between reaches and storage areas. CSECT writes tables of cross section properties and reach connection data to a binary file that is read by RDSS and UNET during the unsteady flow simulations. CSECT must be run prior to the first unsteady flow simulation and subsequently only when the geometry file is modified. In addition to the CSECT input file, another input file must be developed containing program instructions and data required by the RDSS, UNET and TABLE programs. This file is denoted by the extension ".BC."

The unsteady flow portion of the UNET system consists of the RDSS, UNET and TABLE programs. RDSS reads and reformats the .BC file, converting boundary condition data from the DSS file into tables that are used by the UNET program. UNET is the unsteady flow simulation component of the system. The TABLE program writes computed hydrographs, maximum water surface profiles, and instantaneous profiles of discharge and stage to a DSS output file. The program UNETMU is a simple DOS point-and-click interface that allows the user to easily select which programs to run and identify input and output files.

Calibration of the UNET Program

Calibration is the adjustment of a model's parameters so that it reproduces observed data to an acceptable level of accuracy. Excluding catastrophic events such as meander cutoffs or a new channel path being cut, the river will pass any given flow within a range of stages. The range of stages is the result of shifting bedforms and unsteady flow looped rating curve effects. Looped rating curves can usually be expected when bed slope is less than 0.5 feet per mile, as is the case in many reaches of the Red River main stem. Unique events such ice jams and levee overtoppings and failures may substantially complicate the calibration process. All observed hydrologic data are subject to error, though stage data are usually the most accurate measured. Discharge data are usually derived from observed stage. Therefore, it is recommended to calibrate unsteady flow models to observed stage hydrographs.

Calibration Inconsistency. The greatest problem with calibration is inconsistency with performance of the model for a particular basin when one observed event can be reproduced but not another. Common sources of error are inaccurate stage and flow records, poor estimation of river and overbank storage, changing river morphology, and accounting for ungaged drainage areas when deriving boundary condition hydrographs.

Calibration Procedures. Calibration in the UNET program can be accomplished in several ways. Manning's "n" values, cross sections and storage area definitions can be changed directly in the .CS CSECT input file to modify conveyance and storage. This can require a prohibitive amount of work if the file is large. Another method of calibration is to insert conveyance change factors and discharge-conveyance relationships in the .BC file on a reach-by-reach basis. This is usually the preferred method of calibration, and it is explained in the UNET user's manual (5). Conveyance can also be adjusted on a seasonal basis, as bedform structure can change as a result of variations in water viscosity caused by changing temperature. Another technique that can be used is to define intact channel ice on a reach-by-reach basis. Intact channel ice increases the wetted perimeter of the channel, which reduces the effective conveyance of the channel. Seasonal temperature variation and channel ice have not been used to calibrate UNET models for the Red River of the North.

DISCUSSION

Application of the UNET program to the Red River of the North provides the capability to show changes in river stages and flow hydrographs for various conditions. The UNET program is able to model changes in hydrology as well as geometry. Results from the UNET model can illustrate how changes in geometric inputs, such as differing levee alignments, affect hydrographs as a flood moves through the basin. Comparisons of the alternatives provide a cumulative impact at any location in the model of making changes in the basin. Insight gained during the spring flood of 1997 will help focus on the best way to proceed with future unsteady flow modeling efforts for the Red River of the North.

Agricultural Levee Model Description

Eleven combinations of flood hydrology and geometric alignment alternatives were modeled for Red River agricultural levee analysis between Grand Forks and Drayton by the St. Paul District Corps of Engineers (6). The results of this modeling effort have not yet been finalized. The four floods modeled were the spring events of 1978, 1979, 1989, and the administratively adopted 100-year flows at Grand Forks, Oslo, and Drayton. The basin geometries used in this study were 1979 as-built conditions, maximum allowable levee development from the Alignment F plan (similar to existing conditions in 1989 and today), and the Alignment F plan with "infinitely high" levees. The Alignment F levee plan is best described in a set of plans and profiles prepared by the North Dakota State Water Commission (7).

The 1979 flood was chosen because it was the flood of record in the basin and the flow rate was only 10% less than the administratively adopted 100-year flood. The 1978 and 1989 floods are believed to approximate the 25- and 10-year floods, respectively. Alignment F was modeled because it approximates existing conditions and represents maximum future levee development. The Alignment F with "infinitely high" levees alternative was included to provide an upper limit of water surface profiles to evaluate downstream effects of levee construction.

Lessons Learned

The Red River model is generally more sensitive to variations and uncertainty in the hydrologic input data than detailed definition of the geometry. Perhaps the most important cause of variation between floods is that the timing and amounts of spring runoff from the tributaries can differ considerably from year to year. This can cause great variations in flood flow in the main stem. Other important random factors that affect spring floods are the occurrence of ice jams and breakout flows. These things can have significant impacts on flow and stage hydrographs throughout the basin. All of these parameters vary from flood to flood and cause the prediction of flood stage at any given location to be very difficult.

Measured hydrologic data, such as stage and flow hydrographs, may not be accurate. Hydrographs for significant portions of the basin were estimated by the drainage area ratio method because of lack of data. This will not account for the actual timing or volume of runoff from the estimated areas. This factor alone probably causes most of the calibration difficulties, and causes the model output results to have more uncertainty at ungaged locations.

Another factor to consider is input data errors and insufficient data. High-water marks and published gage datums can be interpreted and/or surveyed incorrectly. The use of cross sections to define channel geometry may not adequately define what is happening in hydraulically complex areas, such as in the vicinity of Oslo. Thus, more cross sections may be needed at some locations.

There is no substitute for becoming as familiar as possible with the hydrology, hydraulics, and geomorphology of the basin being modeled. Past flood events need to be analyzed and compared to current data. Field visits provide an understanding of the basin that cannot be obtained in any other manner. Field visits can sometimes be the only way to resolve complex computational problems.

Recommendations

The large number of storage cells in the agricultural levee models (127 for the 1979 geometry, 139 for Alignment F) may have been unnecessary and could imply an accuracy of the model results that does not exist in areas where there are no gage data. A suggested minimum number of cells required would be to put one cell between each adjoining river reach and major ditch, rather than defining cells strictly by the county roads. More cells could be used where necessary for special studies. A good basinwide model will need more hydrologic data boundary condition locations and a lower number of storage cells. Use more storage cells where differing levee alignments need to be evaluated and less cells everywhere else for additional reaches in future models. Using less cells will make the model run more quickly and will cause less computational problems.

For a basinwide study of the main stem, concentrate on improving hydrologic data. A system of 16 data collection platforms (DCP) exists on the Red River main stem from Wahpeton to Drayton, on the Sheyenne and Park Rivers in North Dakota, and on the Red Lake River in Minnesota. It is estimated that 21 additional DCP units would be needed to implement a real-time UNET model for the Red River main stem. Many of the recommended locations are at existing and discontinued U.S. Geological Survey gage sites. A DCP is point source of stage information that usually coincides with a USGS gage which is part of the Data Collection System (DCS) administered by the National Environmental Satellite, Data, and Information Service. After the data are collected electronically at the gage location, they are transmitted directly to the U.S. Geostationary Operational Environmental Satellite (GOES) system. The information is then relayed through GOES to the DCS Automated Processing System (DAPS) under contract to the National Oceanic and Atmospheric Association (NOAA). The DAPS is a large dual-computer-based system located at the NOAA Command and Data Acquisition facility in Wallops, Virginia. The DAPS continually broadcasts all incoming DCP data over a leased channel on a domestic communications satellite (DOMSAT). DOMSAT Receive Station computers at remote user sites continuously receive, archive, and process the DOMSAT signal. These data collection sites would provide valuable input to real-time observation and modeling of the river system during flood events and help to evaluate the downstream effects of reservoir releases.

REFERENCES

1. U.S. Army Corps of Engineers, St. Paul District (1989) Selection of a Numerical Model for the Red River of the North Main Stem, Grand Forks, North Dakota to Canada.
2. U.S. Army Corps of Engineers, Hydrologic Engineering Center (1990) Red River of the North UNET Application, Project Report No. 91-01.
3. U.S. Army Corps of Engineers, Hydrologic Engineering Center (1987) COED, Corps of Engineers Editor, User's Manual.
4. U.S. Army Corps of Engineers, Hydrologic Engineering Center (1995) HEC-DSS User's Guide and Utility Program Manual.
5. U.S. Army Corps of Engineers, Hydrologic Engineering Center (1995) UNET: One-Dimensional Unsteady Flow Through a Full Network of Open Channels, User's Manual, Version 3.0, adapted from documentation prepared by Dr. Robert L. Barkau, P.E.
6. U.S. Army Corps of Engineers, St. Paul District (1996) Red River of the North UNET Modeling Application, Draft Report.
7. North Dakota State Water Commission (1991) Red River Dikes, Project No. 1638, plans and profiles.

AN OVERVIEW OF THE RED RIVER VALLEY WINTER OF 1996–1997

Leon F. Osborne, Jr.
Regional Weather Information Center, University of North Dakota
Grand Forks, North Dakota 58202

INTRODUCTION

The flat terrain comprising the floor of ancient Lake Agassiz provides the setting for periodic Red River flooding. It is, however, the annual variability of the weather that determines in any single year the nature and extent of the river's flooding. The unusually high number of winter storms in combination with physical characteristics of the land and atmosphere provide the keys to understanding the Red River flood of 1997. Five of these characteristics are summarized by Williams (1) as gradient, river direction, fall precipitation, snow accumulation, and soil condition. These three characteristics, with atmospheric dependence, plus an additional characteristic of spring snowmelt conditions, that are the subject of this paper.

REGIONAL CLIMATIC CONTROLS

The Red River Basin is located in a humid continental cool-summer climate (2). The continentality of the climate results in significant inter- and intra-annual variability in temperature and precipitation. The majority of the region's total annual precipitation occurs during the summer months through convective precipitation. The Rocky Mountains serve as an effective barrier to maritime Pacific moisture leaving the Gulf of Mexico as the primary moisture source. The absence of mountain barriers to the north and south results in frequent incursions of low-moisture continental polar and arctic air masses from the north and high-moisture maritime tropical air masses from the south.

Regional precipitation is influenced by the prevailing jet stream position, which guides the track of extratropical cyclones across North America. Across the Northern Plains, the orientation of cyclone tracks are partitioned into two primary categories – northwesterly and southwesterly flow. Each of these categories provides for different precipitation and temperature profiles based upon air mass position and moisture availability.

Northwesterly Flow

The northwesterly flow is characterized by anticyclonic synoptic-scale flow from the Canadian Rocky Mountains to the Great Lakes area. Cross-barrier flow at midlevels of the atmosphere in southwestern Canada results in lee cyclogenesis in southeastern Alberta. As baroclinic waves cross the mountain crest, the Alberta cyclone moves swiftly to the southeast following the mean jet stream path. Cyclonic rotation from the surface through 850 hPa (850 mb) results in strong southerly flow in advance of the system. The presence of background anticyclonic synoptic-scale flow minimizes the presence of maritime tropical moisture downstream of the cyclone. Thus, little moisture is available to support widespread heavy precipitation, as the swift movement of the cyclone does not permit adequate time for moisture advection to be drawn northward from the Gulf of Mexico. The anticyclonic synoptic flow does enhance the presence of colder polar and arctic air within the northerly flow following the Alberta cyclone. Typical precipitation across the Red River Basin associated with these storm systems is limited to brief heavy snow within the warm-air advection in advance of the low, with blowing snow and ground drifting after low passage within the cold-air advection.

Southwesterly Flow

The southwesterly flow is typified best by the development of strong extratropical storms in southeastern Colorado. These Colorado cyclones have significant upper-level support from the broader cyclonic synoptic-scale flow extending from the crest of the southern Rocky Mountains into the Great Lakes area. The existing cyclonic flow across the Southern and Central Plains supports the development of a low-level jet stream in the layer from the surface to 850 hPa (850 mb) during lee cyclogenesis. This low-level jet stream provides significant moist, warm air advection from the Gulf of Mexico in advance of the easterly moving Colorado cyclones. This provides ample support for widespread precipitation in advance of the surface low-pressure center. Due to conservation of angular momentum of the 500 hPa (500 mb) airflow associated with the lee cyclogenesis, the Colorado cyclones move briefly to the southeast from Colorado before turning on a northeasterly track. As the surface low-pressure centers move into the Central Plains, increasing cold-air advection behind the extratropical cyclone draws polar and arctic air masses southward. The strong thermal gradient across the Colorado cyclone results in continued growth due to baroclinic instability.

Frequency of Occurrence

The relative annual frequency of Alberta cyclones to Colorado cyclones typically determines the extent of total cool season precipitation across the Northern Great Plains. While Colorado cyclones are generally less frequent than Alberta cyclones, it is the Colorado cyclones that generally provide the potential for excessive precipitation totals. On an annual average, Alberta cyclones occur with three times greater frequency than Colorado cyclones according to Whittaker and Horne (3). The monthly frequency of Colorado cyclones peaks during the seasonal transition months of March through May and again in October and November. The highest monthly frequency is roughly two occurrences during April.

WINTER OF 1996–1997

Fall Precipitation

Continuing an above-normal wet cycle that began in 1993, fall precipitation was above normal across eastern North Dakota and western Minnesota. After a wet June and early July, the summer of 1996 became seasonably hot and dry during August and early September. Rainy conditions during September and October produced above normal precipitation, resulting in abundant soil moisture before winter. These wet conditions further reduced surface water holding capacity across eastern North Dakota and western Minnesota. Heaviest precipitation during September occurred along the James, Sheyenne, and the southern Red River, with a local maximum in Dickey County located in southeastern North Dakota. The North Dakota Agricultural Weather Network observation station at Oakes, North Dakota, reported a monthly total of 7.10 in (18.0 cm) of rainfall for September.

A late October Colorado cyclone provided the first significant snowfall across portions of North Dakota. Unusual late-season severe thunderstorms and tornadoes occurred from central Minnesota into the central Red River Valley (4). These storms produced heavy rainfall across the central and southern Red River Basin. Further north and west, the precipitation fell as heavy, wet snow with amounts in excess of 18 in (45.7 cm) common from extreme northeast North Dakota into central North Dakota.

Snow Accumulation

The winter of 1996–1997 was significant for the frequency of major snowstorms. After an Alberta cyclone produced moderate rain and snow across eastern North Dakota on 6 November, another Colorado cyclone on 16-17 November 1996 provided the first of nine blizzards (Table 1) to cross the Red River Valley during the winter. Cold temperatures followed the passage of the Colorado cyclone, assuring that all subsequent precipitation until March would fall as frozen precipitation.

Blizzard Occurrences
16-17 November 1996
15-18 December 1996
20-21 December 1996
3-4 January 1997
9 January 1997
22 January 1997
4 March 1997
13 March 1997
4-6 April 1997

Table 1. Blizzard Occurrences in Eastern North Dakota during the winter of 1996-1997.

By 13 March 1997, Grand Forks had eclipsed the total snowfall from the previous winter (Figure 1). A record for winter snowfall accumulation was set at all Class A reporting

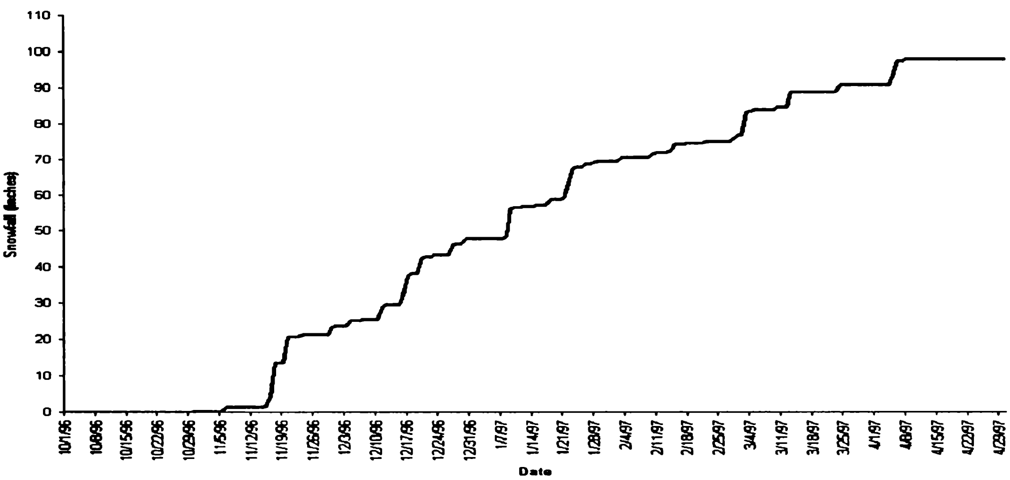


Figure 1. Accumulated snowfall for winter 1996-1997 at Grand Forks, North Dakota. Snowfall amounts in inches as measured at the eastern North Dakota National Weather Service office.

stations in central and eastern North Dakota except for Minot. Most of the winter storms were the result of Alberta cyclones developing in the northwesterly–westerly flow. These systems can produce near-blizzard or brief blizzard conditions, but yield little significant snowfall accumulation. However, during the 1996–1997 winter, Alberta cyclones produced snowfall amounts in excess of 6 in (15.2 cm) (Figure 2) three times. These storms were unusual, in that while progressing across North Dakota, the normally fast-moving systems would slow to a near halt as a result of strong upstream ridging. While this delay was only at most for 18 hours, this provided sufficient time for greater moist, warm air advection to enter the region. This enhanced intensity of the storm resulted in greater snowfall accumulation across eastern North Dakota. The higher air temperatures exhibited prior to surface low-pressure passage also permitted the water content of the snow to be greater. The cold temperatures typical for winters in the Red River Valley result in a general ratio of 20:1 snow-to-water equivalent. In extreme situations, this ratio can be as high as 40:1. However, on three occasions this past winter, the ratio for snowfall to water equivalent was less than 15:1 in the vicinity of Grand Forks, North Dakota.

April Blizzard

The most extreme conditions experienced during the winter season of 1996–1997 came during the period 4-7 April (5). A major winter storm developed in association with a deep Colorado cyclone. The contrast of cold arctic air moving southward from Saskatchewan and deep warm air from the Central Plains resulted in strong baroclinic instability and rapid intensification of the Colorado cyclone. Minimum central pressure observed was 974 hPa (974 mb) mean sea level in central Minnesota early on 6 April. The strong pressure gradient about the cyclone center was resulting in wind gusts in excess of 80 mi/hr (129 km/hr) across much of northeastern North Dakota. The snowfall associated with this storm was concentrated in a band extending from northwestern South Dakota to south central Manitoba. Storm total accumulations in southwestern North Dakota were in above 30 in (76.2 cm) over the 3-day storm. Severe drifting of snow driven by the high winds resulted in numerous reports of 20 ft (6 m) high drifts.

The distinguishing feature of this storm, besides the deep central pressure, was the deep layer of warm moist air, which advected northward in advance of the surface cyclone. The track of the surface cyclone was from the southwest across northeastern South Dakota. Warm frontal rain bands pushed into the southern Red River Valley on the evening of 4 April, producing total rainfall in excess of 1.50 in (3.8 cm) across southeastern North Dakota and west central Minnesota. The deep tropical air mass was held aloft by cooler surface air, producing a layer of above-freezing temperatures to 700 hPa (700 mb). Strong northerly winds produced below-freezing surface conditions. This cold air advection continued to lift the warm layer, resulting in a widespread area of freezing rain across eastern North Dakota and northwestern Minnesota.

Although snowfall amounts for Grand Forks reflect only 4 in (10.2 cm) of accumulation (Figure 2), rainfall accumulations were over 1 in (2.5 cm). Heavier rainfall amounts were reported in the southern Red River Valley, with Fargo measuring 1.36 in (3.5 cm). All precipitation amounts are estimations, as the freezing rain made accurate measurements difficult.

River Direction and Spring Snow Melt

The direction of flow of the Red River is significant to flooding only with respect to spring flooding. This is typically due to the greater warming in the southern Red River Valley. The cause of this thermal gradient is related to the increased solar insolation received at lower latitudes. For spring 1997, the increase in temperatures can be seen in the mean daily temperatures between two weather observation stations in eastern North Dakota (Figure 3). St. Thomas (STT) is located in south central Pembina County and represents the northern Red River Valley. Wyndmere (WYN) is located in west central Richland County and represents the southern Red River Valley. The warmer mean temperatures for Wyndmere are the result of warm air advection from locations further south and a greater contribution of solar insolation to raising the sensible temperature. The latter becomes more significant as bare fields become exposed with melting snow.

The difference in temperature across the basin becomes more critical during periods of rapid melting and runoff when northern portions of the Red River are still frozen. The likelihood of a rapid melt and runoff is increased with colder temperatures during late March and early April. March 1997 began with two blizzards before becoming unseasonably dry with near normal temperatures (Figures 2 and 3). This was similar in pattern to March and April 1996, when excessive snowfall accumulations also posed a significant flooding threat. The much below normal temperatures that followed the April 4-6 blizzard resulted in reduced field runoff, but also slowed the melting process by 7-10 days. The temperatures slowly rebounded to near normal conditions by mid-April, with no additional precipitation occurring.

SUMMARY

The winter of 1996-1997 was exceptional in that it produced a high number of strong winter storms containing significant amounts of liquid water. This paper provides an overview of the winter storms and relates them to the general storm tracks responsible for producing the majority of the region's cool-season precipitation. The occurrence of major precipitation events at the beginning and end of the 1996–1997 winter season provided support for the continuing above-

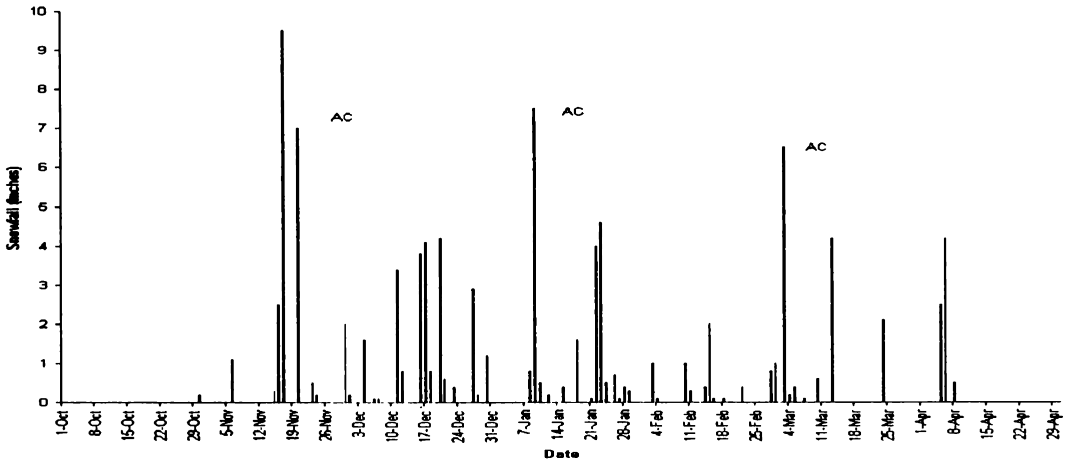


Figure 2. Daily snowfall amounts for winter 1996-1997 at Grand Forks, North Dakota. Alberta cyclones (AC) and Colorado cyclones (CC) are denoted for major storms. Snowfall amounts in inches as measured at the eastern North Dakota National Weather Service office.

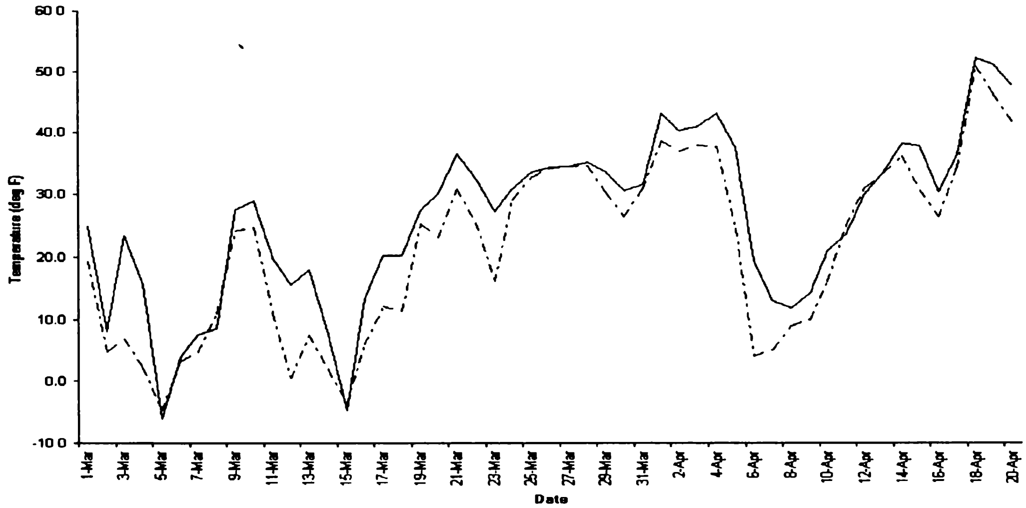


Figure 3. Mean daily temperature profiles for northern Red River Valley location (St. Thomas – STT) and southern Red River Valley (Wyndmere – WYN). Temperatures are in degrees Fahrenheit.

normal precipitation trend since 1993. The level of total snowfall and its high liquid water content exceeded the levels of previous years. This anomalously high amount of precipitation that occurred made the flooding potential extreme for spring 1997.

The analysis of data from this past winter will require additional years of study to better understand the relationship of interannual climate variability and the representativeness of the past winter to the long-term mean. Further, additional use of a nonstandard dataset will be necessary to capture a more complete spatial distribution of winter precipitation.

REFERENCES

1. Williams, J.C. (1997) The Floods of 1997: A Special Report, North Dakota State Water Commission, pp 27.
2. Critchfield, H.J. (1983) General Climatology, 4th edition, Prentice Hall, pp 180-226.
3. Whittaker, L.M., and Horn, L.H. (1981) Geographical and Seasonal Distribution of North American Cyclogenesis, 1958-1977. Mon. Wea. Rev., 109, pp 2312-2322.
4. Bramer, B. (1997) An Examination of the Upper Midwest Progressive Tornado Outbreak of 26 October 1996, Proceedings of the Second Workshop on Northern Plains Convective Storms, Grand Forks, Mar. 20-21, pp 1-2.
5. Block, C., and James, M.H. (1997) Hannah Summary for 4-7 April 1997, Technical Report, UND Regional Weather Information Center, p 15.

WATER QUALITY IN THE RED RIVER OF THE NORTH DURING THE SPRING FLOOD OF 1997

M.E. Brigham and D.L. Lorenz*
U.S. Geological Survey
2280 Woodale Drive, Mounds View, Minnesota 55112

Sources of contamination to the Red River of the North and its tributaries during the spring flood of 1997 included: dead animals, feedlots, municipal sewage treatment systems, petroleum from flooded fuel-oil tanks, cars, and possibly industrial and agricultural chemicals. Several agencies (North Dakota State Health Department, Minnesota Pollution Control Agency, and U.S. Geological Survey [USGS]) sampled the Red River at several locations weekly for nutrients, pesticides, volatile organic compounds (VOCs), and fecal bacteria to document water quality conditions. Environment Canada sampled the Red River of the North at Emerson, Manitoba.

In the Red River Basin, nutrient levels typically reach their annual maxima during spring-snowmelt runoff (phosphorus can also be high during summer runoff events). Maximum dissolved nitrate nitrogen concentrations measured during the flood (1.5 mg/L upstream of Fargo, 1.1 mg/L at Grand Forks, and 1.0 mg/L at Pembina) were lower than concentrations measured from 1993-1995 during spring-snowmelt runoff (3.4 mg/L upstream of Fargo, 3.7 mg/L at Grand Forks, and 4.6 mg/L at Pembina). Dissolved ammonia and organic nitrogen and total phosphorus concentrations were similar to those measured from 1993-1995.

Several pesticides were detected, but at low concentrations characteristic of spring runoff periods. Atrazine, deethylatrazine, and metolachlor were detected in all samples from the Red River of the North. The maximum concentration of atrazine (0.145 μg/L upstream of Fargo) was much greater than the maximum measured during spring runoff from 1993-1995 (0.033 μg/L upstream of Fargo).

Petroleum (gasoline or fuel oil) was observed on the river surface and VOCs (alkylbenzenes and naphthalene) were detected in samples. In some samples, traces of chlorinated solvents were detected (all concentrations were less than 1 μg/L). Other VOCs occasionally detected were methyl ethyl ketone (0.4-3.7 μg/L), and acetone (1-2 μg/L).

Fecal coliform and fecal streptococci are indicators of contamination from animal or human waste. Fecal coliform counts were 81 colonies/100 mL upstream of Fargo, 149 at Grand Forks, and 26 at Pembina, North Dakota. Fecal streptococci counts during the flood were (2100 colonies/100 mL upstream of Fargo, 10,900 colonies/100mL at Grand Forks, and 9380 colonies/100 mL at Pembina). Fecal streptococci levels were higher than recent years (1982-94) (1500 colonies/100 mL upstream of Fargo and 720 colonies/100 mL at Pembina). The ratios of fecal coliform to fecal streptococci colonies were less than 0.6, which indicates that contamination was probably from agricultural sources.

FLOOD PROTECTION IN THE NETHERLANDS

Jos Kuijpers and Jan C. Janse*
The Netherlands Directorate-General for Public Works and Water Management, South Holland Department
Postbu 556, Boompjes 200, 3000 AN Rotterdam, The Netherlands

INTRODUCTION

Since the beginning of the Christian era, since the Roman occupation in fact, the Netherlands has had to fight against the threat of flooding from storms on the North Sea and high water in the delta of the rivers Rhine, Maas, and Scheldt; we have been fighting the water for so long that it is now in our blood. The very first areas of land to be reclaimed, known as polders (Figure 1), were protected against inundation by dikes, dunes, and sometimes high ground. Such protection can be a matter of life and death: the Netherlands is a very low-lying country. Without the dikes, dams, and dunes, large parts of the country would frequently be flooded.

Over the centuries, the defenses were regularly strengthened in the wake of a flood or whenever flooding seemed imminent. History shows, however, that when conditions are not so pressing, safety considerations tend to lapse and few measures are taken to maintain or improve the defenses. Periods of intense activity to control the water alternate with periods of inactivity when maintenance is poor, buildings are erected in unprotected areas, the rivers' capacity to discharge water is taken for granted, and contingency plans and precautions are ignored. Communities apparently only snap into action when faced with a real danger.

In the Netherlands, the importance of safety was brought home by widespread flooding in the river regions in 1926 and the flooding of the delta region with severe loss of life and damage to property in 1953. More recently, an area along the River Maas that was not protected by dikes was threatened with flooding in 1993 and 1995. When the Rhine and Maas Rivers were in danger of bursting their banks, people and livestock had to be evacuated en masse from the polders to higher ground elsewhere in the country. Only emergency measures could prevent the flooding, and even then it was touch and go.

To date, safety measures have generally taken the form of building and strengthening flood defenses. In addition, rivers have been regulated, controlled, and straightened for other reasons, for example, inland shipping and military defense, which has improved safety by increasing the rivers' discharge capacity. With stronger flood defenses and greater safety, the investments made behind the dikes have increased. As the defenses have improved, however, the water level has risen, and should the dikes fail, the extent of the flooding in the surrounding polders would be greater.

WHAT HAS BEEN ACHIEVED?

Following the disaster of 1953, the Delta Plan was conceived and embodied in the Delta Act. In the decades that followed, substantial defenses were built in the delta region along the Rhine estuary and along the coast, culminating in the completion of the storm surge barrier in the New Waterway in 1997. Adequate defenses are now in place to protect against storm floods.

In tandem with the coastal defenses, a start was also made on improving the dikes along the rivers. Progress was delayed, though, by growing public opposition over the years, long-winded legal procedures at the planning stage, and lack of capital. The high water levels in 1993 and 1995, however, made us painfully aware of how precarious the safety of the river polders was. This led to the Large Rivers Delta Plan, which will raise safety to the required standard by the year 2000. There are two stages to this plan:

- The least safe sections of the dikes (flooding probability of more than 1/100 per annum) will be strengthened in 1995 and 1996, with a possible extension to 1997.
- Where possible, most of the remainder of the dike strengthening program will be completed by 2000.

Despite the extremely tight planning, there is every reason to expect the targets to be achieved for the most part.

Protection against flooding has been given a legal basis in the Flood Defenses Act. This act stipulates the protection against inundation to be afforded by all dike systems in the Netherlands. The safety standard is expressed as the probability per annum of the highest water level exceeding the design standard for each section of the flood defenses. The design standard varies from 1/10,000 per annum for central Holland to 1/1250 per annum for the river regions. This variation reflects differences in population density, the value of the property to be protected, the height of the polder, and the nature of the threat. The nature of the threat is particularly important, in that the threat of a river flood can be predicted far earlier than that of a sea flood and a saltwater inundation causes far more damage than a freshwater inundation. In addition to establishing these standards, the act requires safety tests to be carried out every 5 years.

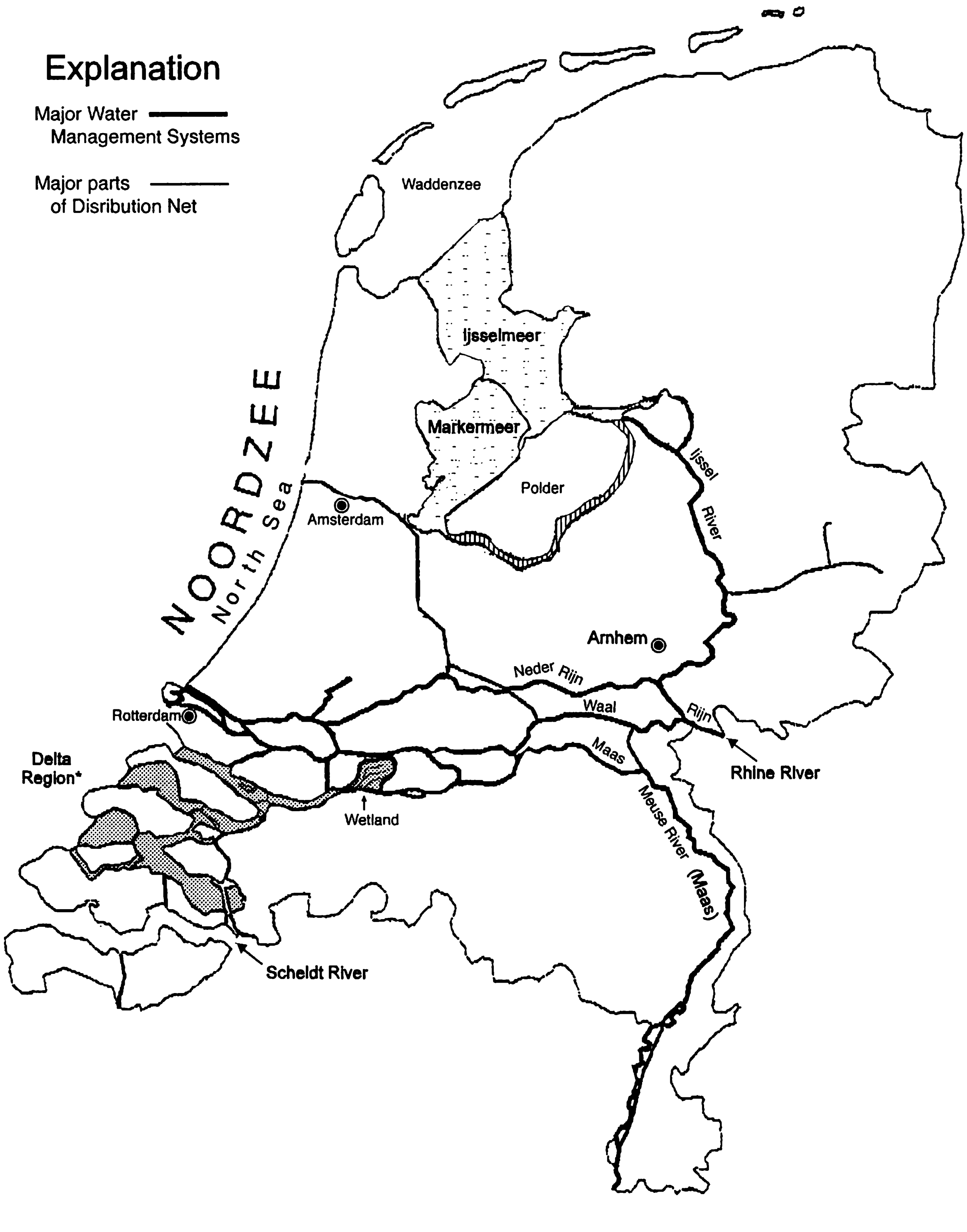


Figure 1. Main water systems in The Netherlands. * = Estuaries protected by storm surge barriers.

The statutory and policy basis for maintaining the required safety standards was provided by the Rivers Act of 1903 and by a ministerial directive entitled Room for the River issued in 1996 (Figure 2). Under the Rivers Act, compensatory measures are required to prevent work in a riverbed raising the water level. The Room for the River directive goes a step further than the Rivers Act in that it is concerned not only with maintaining a river's water level but also with maintaining and increasing its discharge capacity, thus improving the safety of the surrounding polders. Activities that are clearly not related to the river, such as housing, will not be permitted; they are ranked in the category "NO – Unless." Activities in the category "YES – Provided" are permitted provided they do not have an adverse impact on the discharge capacity; if they do, long-term compensation is required. Furthermore, the directive sets minimum safety standards to limit the harmful effects of new activities being conducted in a riverbed.

The policy that has evolved to guarantee protection against storm surges is set out in the 1995 document entitled "Coastal Balance." This document confirms the principle of continuous maintenance of the coastal zone and sets targets for the retention and strengthening of the coastal system. The volume of sand on beaches and in the shallows before the coast is maintained by regular replenishment. Human action that undermines the defenses will not be permitted unless compensatory measures are taken. Even though the area of application is different, this policy clearly mirrors the elements of the Room for the River directive.

The threat of floods in 1993 and 1995, which was also faced by countries upstream, particularly Germany and Belgium, increased awareness that safety plans had to be coordinated with upstream development plans and river works. In an ideal world, safety plans would be worked out and established for entire river systems. In former years before 1993, there had been some exchange of information and a certain degree of cooperation, but there had been no joint planning. Today there is. The strategy and resultant actions for the protection of the Rhine Basin are worked out by the high-water working party of the International Rhine Committee (IRC); the high-water working party of the International Maas Committee (ICM) performs a similar function for the Maas Basin. Spatial planning in both river basins, an essential element for continued protection against high water, is monitored by the transnational working party for Rhine–Maas spatial planning and water management.

In the past, the accepted answer when flood defenses proved inadequate was to build higher and sometimes heavier structures. Experience and knowledge of the local situation were vital. In this century, as the need arose for a more scientific approach to flood protection, research centers were set up to study the flow of water in rivers and along the coast and the structural properties of flood defense constructions. These centers have applied their measurements and hydraulic and mathematical knowledge to create statistical models of discharges, fluvial and coastal flows, and the strength of flood defenses. Provided these models are adequately defined and verified, we can use them to determine to a reasonable degree of certainty whether the safety targets have indeed been achieved. It should be stressed that there can be only a reasonable degree of certainty. Precise answers cannot be given. All results are inaccurate to one degree or another, and it is essential that both the scientists and the public are fully aware of this. There is always a limit to human knowledge.

NEW DEVELOPMENTS

You would be forgiven for thinking that by the year 2000, the magical year 2000, the Netherlands would have achieved its safety targets and that we would then be able to sit back, tired but content in the knowledge that all we had to do was maintain what we had already achieved. Such complacency, if it exists, must be rooted out. The facts and developments considered below are not only cause for concern—they require us to redouble our efforts.

Statistical Extremes

The extreme water levels experienced in 1993 and 1995 were not included in the calculation of the maximum discharges for the Rhine and Maas and the water levels based on them. Their addition to the list of high water levels would lead to an increase in maximum discharge values. Since the very next periodic test of the strength of the flood defenses will consequently have to be based on higher water levels, some of the flood defenses strengthened before the year 2000 may prove inadequate for the new conditions.

Climatological Changes

It is thought that the greenhouse effect may raise the average sea level by 50 cm (19.7 in) per century (the current rate is 15 cm [5.9 in] per century), while changes in precipitation patterns and intensities may increase the extreme discharges of the Rhine and Maas by about 10%. Changes of such a magnitude will undoubtedly require a reconsideration of the safety approach adopted in the Netherlands.

Increased Risk Of Flooding

A number of polders are subsiding by about 10 to 15 cm (3.9 to 5.9 in) per century as a result of the extraction of gas and the erosion and oxidation of peat layers, which in turn requires the water level in the polders to be lowered if the land is to remain suitable for farming (it must be possible to

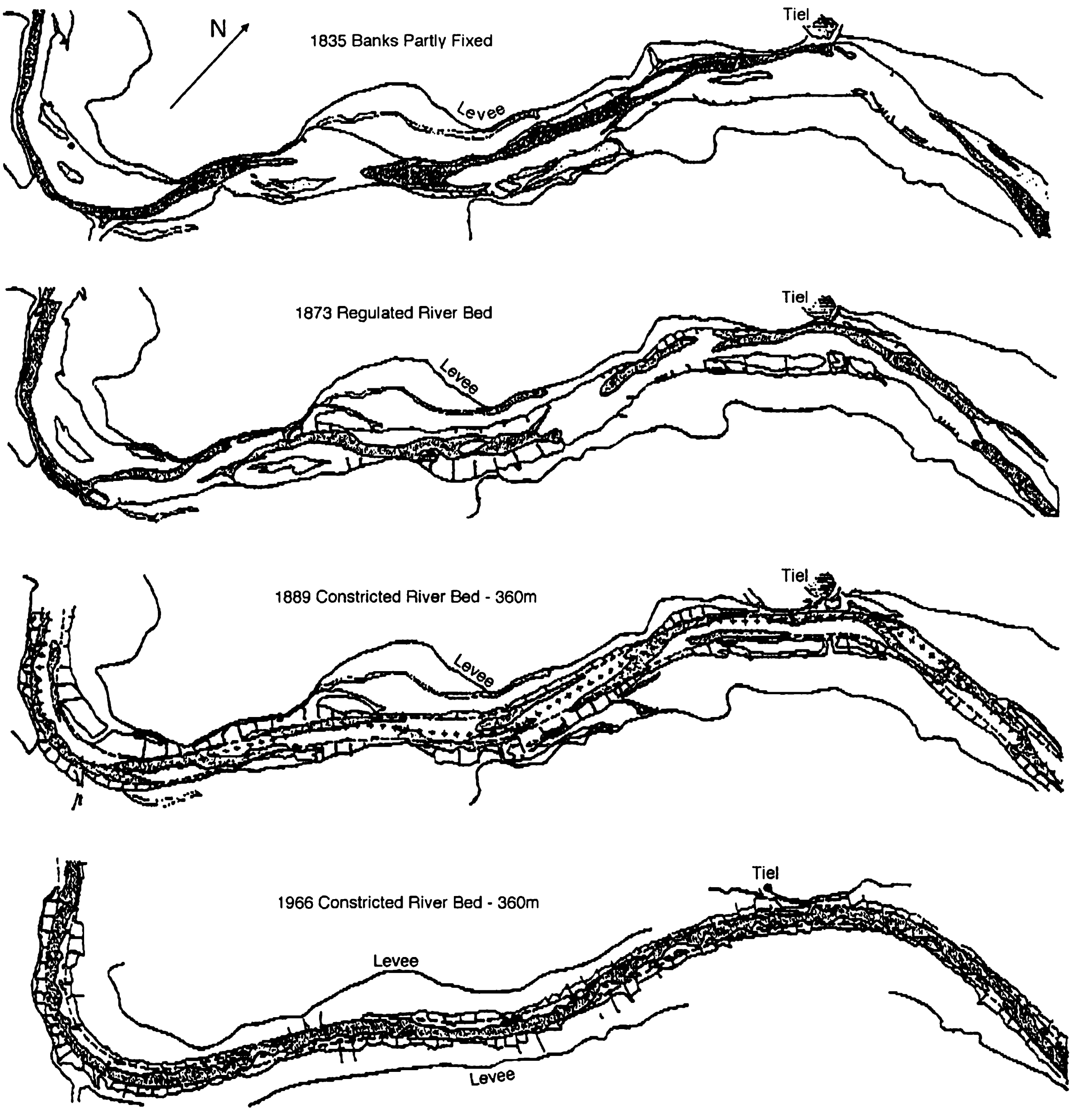


Figure 2. History of the improvements on the Section 910-930 km of the River Waal.

work the soil with ever-heavier machinery). In addition, the value of the property being protected is being increased by economic expansion and greater investment in the polders, while there is still no end in sight to the growth of the population. Although these developments do not increase the threat of flooding, they do increase the scale of the risk.

Safety Philosophy

To date, safety has been expressed as the probability of a water level being exceeded, in other words, the probability of a certain load being exceeded. This approach says little about the actual risk of inundation. If the actual risk were known, it could be compared with other risks facing society (e.g., nuclear power stations, traffic, industrial explosions) and included in an integrated risk philosophy. The possibility of adopting a more sophisticated attitude to safety has already been provided by the Flood Defenses Act. The Technical Advisory Committee for Flood Defenses is currently coordinating research work directed at generating methods to analyze the real risk of polders being inundated, which should be ready by the year 2000.

Strengthening Dikes is Not the Only Way to Achieve Safety Targets

In the Netherlands, where the properties of the soil below the dikes are often relatively poor and many culturally important buildings are located on or around flood defenses, strengthening the flood defenses has become a complex and extremely expensive business (owing to the complicated procedures in place to protect the many interests). Since the pressure on the flood defenses can be reduced by lowering the maximum discharges and by lowering the water levels associated with those discharges, it has been realized that a far broader analysis of all factors is necessary if we are to arrive at the right balance between safety and flooding. The potential needs to be explored for the following:

- Constructing retention areas in the upper courses of the rivers. This may be possible in thinly populated regions.

- Implementing retention measures in urban and rural areas to prevent the rapid runoff of surface water and groundwater.

- Lowering the major bed of the rivers; this would appear to be a simple technical measure, but in practice it is made extremely complicated by designation/use and ownership problems and becomes very expensive if the upper layer of the floodplain is contaminated. Where nature reserves can be created, a win–win situation occurs.

- Lowering and widening the minor bed of the rivers; opposition from shipping companies would probably rule this option out on composite rivers such as the Rhine but on simple and, in particular, canalized rivers such as the Maas it could be applicable.

- Lowering the hydraulic roughness by removing obstacles (undesired structures and overgrowth).

- Broadening the major bed of the rivers: this measure would be possible only in areas where there is relatively little housing on and around the dikes.

- Increasing the strength of the coastal defenses. If we accept that the greenhouse effect and the attendant rise in the sea level are very difficult to control owing to the worldwide nature of the problem, increasing the strength of coastal defenses would seem to be the only solution.

- Reducing waves and wave fetches in areas where this is relevant.

Accuracy of the Models

Every variable used in a model has a certain degree of inaccuracy, while the laws of physics used in the model only approximate, often in simplified form, the processes that occur in nature. The inaccuracies inherent in the simulation of an extreme situation may be reduced to a minimum by means of definition and verification, even if the event being modeled has never occurred before, but it will never be possible to make forecasts with absolute certainty. Continuous definition and verification of the models, particularly those used for the strength of dikes, will increase our ability to put safety forecasts into perspective and deal with the residual uncertainties.

CHALLENGES FOR THE FUTURE

It can be concluded from the above that a number of daunting challenges await us in the future. The most relevant ones are summarized below.

- The program to strengthen the river dikes must be completed by the year 2000: this is a question of carrying out existing plans, for which both the procedures and the preconditions have already been established.

- Following research of the discharge properties of the entire Rhine and Maas River Basins, international consultation must be held to determine the maximum discharges and the hydrograph of the discharges at the borders of the Netherlands.

- An optimum balance of measures must be found within the framework of the Room for the River guidelines to increase the discharge capacity of the rivers on the one hand and strengthen the flood defenses on the other. This optimum should not be defined solely in technical or financial terms but also by a vision of the required functions of the river, delta, and coastal regions. In determining the optimum balance, account should be taken of the changes in the conditions described above.

- A coordinated body of legislative and policy tools must be established to optimize water management and spatial planning in the river regions. In particular, the physical use of the region should be such that the required safety concept can be realized and maintained, both now and in the more distant future. Current legislative and policy tools should be analyzed to determine whether they will allow the ideas advanced in the Room for the River directive to be put into practice.

- An implementation plan must be drawn up for after the year 2000 so that safety targets can be effectively maintained and not slowly eroded if new threats fail to arise for some time.

- We have learned from the events of 1993 and 1995 that the damage caused by high water can be significantly limited if there is an adequate warning system and contingency plans are regularly tested. Such plans must of course be capable of dealing with a real inundation. And an inundation may occur; it may not always be possible to prevent a disaster, even if all the plans work, because design conditions can be exceeded in very extreme conditions and because nature does not always lend itself to forecasts and calculations. To fine-tune the contingency plans to the real conditions of a flood, a Flood Information System (HIS) is being set up to provide information on the development of an inundation. The system consists of a predictive component (hydraulic calculation of inundations) and a monitoring component that is fed with up-to-date information from the scene of the disaster.

CONCLUSION

From the beginning of the Christian era to the present day, we have gained 20 centuries' experience in fighting water. But we must not slacken our efforts to maintain and further improve our protection against flooding in the 21st century. History has shown that there will be many starts and stops, for our current knowledge and behavior is unfortunately less than the accumulated wisdom of the past 20 centuries.

FLOOD OF THE CENTURY AND FLOOD MANAGEMENT

Todd Sando
North Dakota State Water Commission, Division of Water Development
900 East Boulevard Avenue, Bismarck, North Dakota 58505

INTRODUCTION

The Red River of the North is synonymous with flooding. Throughout this century, federal, state, and local agencies and private concerns have conducted studies and implemented solutions in an effort to control Red River floodwaters. In spite of these efforts, tremendous damages continue to occur. The physical characteristics of the Red River make destructive flooding inevitable. These characteristics include a main river channel that is undersized in relation to the floodplain, the small gradient of the main river channel, the flatness of adjacent land, orientation of the river from south to north, and a floodplain formed by the bed of Glacial Lake Agassiz rather than the regime of the river. Urban development and human habitation of the Red River floodplain have compounded public exposure for devastating flood losses.

Devastation along the Red River was staggering in 1997 and was well documented by media throughout our country. News story after news story discussed flooding problems, impacts, and hardships, while little attention was given to positive stories relating to flood reduction. This paper provides a perspective on the 1997 flood, statistically comparing it to other floods; highlights several successful flood control measures; and discusses future projects.

1997 FLOOD

During no single year on record since the settlement of North Dakota have Red River Valley residents witnessed floods equal to the magnitude of those in 1997. Disastrous overland flooding inundated homes and communities; caused massive power outages; disrupted water, sewage, and electrical services; blocked major transportation routes; and caused the evacuation of more than 50,000 people in the Fargo and Grand Forks areas. The 1997 flood was the largest flood in the period of record at all the gaging stations on the Red River mainstem in the United States. Many Red River tributaries also experienced record flooding. By an unusual coincidence, the previous flood of record at the major cities in North Dakota occurred 100 years ago, in 1897. This year's peak flows in Fargo and Wahpeton were only slightly larger than in 1897, while the Grand Forks and Drayton peak flows were much larger than the previous record. Grand Forks has the longest period of record of any Red River gaging station in the United States. Records at Grand Forks started in 1882. Canadian records on the Red River extend further back, to 1826. For comparison, the 1997 flood at Winnipeg is only the third largest flood in the Winnipeg record. Based on our limited period of record, a future flood will undoubtly exceed the flood of 1997.

What Was the Source of All the Water in the Red River?

The Red River drains 45,000 mi^2 (116,550 km^2) in North Dakota, South Dakota, Minnesota, and Manitoba. Approximately 36,500 mi^2 (94, 535 km^2) of the drainage area is in the United States. This does not include the 3580 mi^2 (9272 km^2) Devils Lake Basin, which has not contributed water to the Red River in recorded history. The Bois de Sioux River drains 2340 mi^2 (6061 km^2) of North Dakota, Minnesota, and South Dakota, or 6% of the Red River drainage in the United States. North Dakota has 18,982 mi^2 (49,163 km^2) that drain into the Red River below the Bois de Sioux. This is 52% of the river's U.S. drainage basin. Forty-two percent, or 15,158 mi^2 (39,259 km^2), of the U.S. drainage basin is in Minnesota. The mean annual runoff increases dramatically from west to east across the Red River drainage basin. Within approximately 100 mi (161 km), the mean annual runoff increases from approximately 0.5 to 4 in (1.3–10.2 cm). In a wet year, these lines shift westward, increasing runoff. A small change from the average runoff is a large percentage change; for example, in the western part of the basin, a 0.5-in (1.3-cm) increase in runoff is twice the normal runoff.

Most of the floodwaters generally originate on the Minnesota side of the Red River Valley. This was especially the case in 1997. Several Minnesota tributaries were at or near flood of record, while only the lower Sheyenne and Pembina Rivers on the North Dakota side were at flood of record. For example, the Red Lake River at Crookston, with a drainage area of 5280 mi^2 (13,675 km^2), had a peak flow of 27,800 cubic feet per second (cfs) (787 m^3/sec), which was identical to the peak flow of the entire Red River at Fargo, which has a drainage area of 6800 mi^2 (17,612 km^2). Floodwaters devastated several smaller communities on Minnesota tributaries, while communities on the North Dakota tributaries had less flood damage. For example, the Park River at Grafton had flows of less than 50% of flood of record, Goose River at Hillsboro approximately 53% of flood of record, and Forest River at Minto only 12% of flood of record. The flood of 1997 would have been significantly worse if the North Dakota tributaries had been near or at record flows.

The following variables contributed to the flooding: 1) soil and watershed condition – since the summer of 1993, the valley had reported above average precipitation and was entering the fifth year of a wet cycle; 2) autumn 1996 precipitation – the Red River Valley experienced heavy autumn rainfall, causing saturated soil conditions prior to winter; and 3) winter 1996–1997 snowfall – extraordinary winter snow accumulated. Grand Forks reported a record 97.9 in (2.49 m) and Fargo reported 117 in (2.97 m) of snow. Although an extraordinarily large amount of snow, unusually difficult winter, and saturated soil conditions are major indicators for flooding, they do not alone guarantee a flood of record. A historic late spring blizzard, with cooler- than-normal temperatures delayed the melting of snow and magnified the flood. With extended winter cold due to the spring blizzard, the runoff occurred suddenly when spring warming finally arrived. This variable, with all the other variables, was the cause of the "flood of record," or, as known to many, the "flood of the century."

The flood severely impacted three sets of sister cities, including Wahpeton–Breckenridge, Fargo–Moorhead, and Grand Forks–East Grand Forks. At these three major locations, the encroachment of the cities caused a damming effect on the Red River. Upstream of the cities, the river was several miles wide. As it entered a city's levee system and numerous bridge crossings, the water was funneled into a narrow floodway. This caused up to a 10-ft (3-m) head differential from the downstream side of the city to the upstream side. Once the water passed through the major cities, it widened back out to several miles wide.

As a result of the physical characteristics of the valley, flooding will continue to cause urban, rural, and agricultural losses. Methods of lessening these economic losses continue to be studied, designed, and implemented. I would like to discuss a few of the successful flood control projects and summarize a couple proposed flood control projects.

Red River Flood Success Stories

West Fargo Diversion. The U.S. Army Corps of Engineers constructed the West Fargo Diversion, with funding assistance from the North Dakota State Water Commission and local sponsors. The diversion removed virtually all of West Fargo from the 100-year floodplain. Previously, approximately two-thirds of the population was in the 100-year floodplain. The project diverts high flows on the Sheyenne River around the west side of the city and prevents overland flows from the north and west from entering West Fargo.

The Flood Insurance Study, published prior to the completion of the diversion (September 1985), states that the 100-year flow was 3300 cfs (93 m^3/sec) and the 500-year flow was 3400 cfs (96 m^3/sec). The Sheyenne River above the diversion at the gaging station near Horace had a peak discharge of 4290 cfs (121 m^3/sec) on April 24, 1997. The peak flow through the diversion, measured at West Fargo, was 4730 cfs (134 m^3/sec). Although determining what impacts temporary dikes may have had is impossible, if this flow had passed through instead of around West Fargo, the flooding in the city could have rivaled the disaster that occurred in Grand Forks.

English Coulee Diversion. The English Coulee Diversion and Dam were a joint project of the North Dakota State Water Commission and the Natural Resources Conservation Service (NRCS) (= Soil Conservation Service). The project stores floodwater behind a dry dam and diverts high flows from the English Coulee west and north of Grand Forks. Based on the Flood Insurance Studies, the project removed between sixty and eighty homes in southwest Grand Forks from the 100-year floodplain. During this spring's flood, the diversion of English Coulee reduced flooding in southwest Grand Forks from would have been caused if the diverted flows had passed through the city in the natural channel. After the dikes failed on the Red River, the project provided conveyance capacity in the English Coulee for water flowing from the Red River west through Grand Forks. This was very beneficial once the temporary dike was constructed on Washington Street, as the water west of the temporary dike flowed out of the city through the English Coulee very quickly. If the dam and diversion had not been in place, much more water would have been in the English Coulee, slowing the exit of the floodwater.

Reservoirs. Lake Traverse, the headwaters of the Boise de Sioux River on the South Dakota-Minnesota border, Lake Ashtabula on the Sheyenne River at Valley City, and Lake Orwell on the Ottertail River near Fergus Falls all reduced flooding by storing floodwater and lowering the peak flow. The peak inflow to Lake Traverse was 15,700 cfs (445 m^3/sec) on April 6. The Corps of Engineers operates the dam to protect Wahpeton and Breckenridge from flooding. When the river stage at Wahpeton reaches 12 ft (3.7 m), releases from the dam are shut off (zero outflow) until the pool level reaches 981 ft (299 m) MSL, at which point water must be released to protect the integrity of the dam. The peak outflow from Lake Traverse was 7000 cfs (198 m^3/sec). The peak inflow to Lake Ashtabula was 6557 cfs (186 m^3/sec), and the peak outflow was 4534 cfs (129 m^3/sec). The peak inflow to Lake Orwell was 2400 cfs (68 m^3/sec), the peak outflow was 1517 cfs (43 m^3/sec).

The reductions in peak flow on the Boise de Sioux and Ottertail Rivers caused a corresponding reduction in flooding at Wahpeton. The reduction in peak flow at Lake Ashtabula reduced flooding in Valley City and other towns along the Sheyenne River and also helped Fargo by reducing overland breakouts from the Sheyenne River toward south Fargo.

FUTURE PROJECTS

Baldhill Dam Raise

The Corps of Engineers is in the process of raising the top of the flood pool at Baldhill Dam by 5 ft (1.5 m). This project will increase the flood storage available behind the dam by 31,400 acre-feet (38,731 km^3) for a total flood storage capability of 71,000 acre-feet (87,577 km^3). Increased storage will reduce the 100-year outflow from the dam from 9300 to 6200 cfs (263–176 m^3/sec), reducing flooding both along the Sheyenne and the Red River.

Emergency Watershed Protection Program

Most of the areas flooded in the Red River Valley are farm lands. The NRCS is providing assistance in the Red River Valley and along the Sheyenne River through its Emergency Watershed Protection (EWP) Program. Under this program, the NRCS will acquire floodplain easements from willing sellers on agricultural lands that have serious recurring flooding problems. Easements will allow unimpeded flow of waters over the easement area, protecting lives and property from future floods. The program will eliminate future disaster payments on land under easement. It will also provide for conservation of natural values, including a fish and wildlife habitat, water quality improvement, floodwater retention, groundwater recharge, open space, aesthetics, and environmental education.

Three categories of floodplain easements are available to the landowner. Category 1 will completely retire land from production and return it to a natural state to optimize flood functions and fish and wildlife values. Category 2 will restrict production of agricultural commodities, but will allow compatible haying, grazing, or silviculture according to conditions with respect to timing, intensity, and duration. Category 3 allows the landowner to retain control of cropping, haying, grazing, or timber harvest, while the United States acquires all other land use, development, and hydrology rights. The payment for the easement will be based on the land value and category, with Categories 1 and 2 being eligible for up to 100% of the agricultural value of the land and Category 3 eligible for up to 50%.

CONCLUSION

Over the last 100-plus years, the Red River Valley has developed into one of the most productive agricultural areas in the world. A majority of North Dakota's population resides in the Red River Valley. Along with the population, most of the economic activity also occurs in the Red River Valley. Despite the many changes and developments by people in the Red River Valley, tremendous natural disasters still occur. Many efforts are under way to lessen future impacts. A few projects have been presented here, and many additional projects are being considered to lessen the potential for future flooding.

Among other proposed projects are the Maple River dam, the Grand Forks levee setback and diversion, many small flood control impoundments, and diverting the Sheyenne River near Kindred. Further study is needed to determine the feasibility, cost effectiveness, environmental impacts, and public acceptance for these and other projects.

RESTORATION OF BOTTOMLAND FORESTS: CHALLENGES AND OPPORTUNITIES

John J. Ball
Department of Horticulture, Forestry, Landscape & Parks
South Dakota State University
Brookings, South Dakota 57007

INTRODUCTION

Flooding along the major river systems in the Great Plains has drawn national attention during the 1990s. The floods along the Missouri and Red Rivers and their tributaries have resulted in the loss of property and the disruption of lives. The aftermath of these floods may result in losses to the bottomland forests from two major factors: damage to the existing forests from flooding and alteration of these forests as a means of reducing future flooding.

The following discussion focuses on the bottomland forests in the Dakotas. Bottomlands are considered to be the low-lying, almost level land along the watercourse. The rivers that cross through the northern Great Plains are among the flattest rivers in North America, with floodplains sometimes extending more than 11 km (6.8 mi). The James River, a tributary of the Missouri River that flows from southwest of Manfred, North Dakota, to Yankton, South Dakota, has an elevation change of only 41 m (134.5 ft) along its 760-km length. The soils on these bottomlands are recent alluvial deposits that show great variability in texture. The soil texture ranges from sand to clay, with these different textures occurring in lenses of varying thickness and depth. Flooding has been a major factor in the development of these soils. As the river meanders, alluvium is deposited on the inside of curves, the points, while eroding the opposite side of the banks. The bottomland soils are also enriched by the deposits of fine-grained sediments that may be deposited to a depth of more than 1 m (3.3 ft) after a major flood event. The topography of the floodplain, river banks, first bottoms, and terraces provide a wide variety of sites with differing soil textures and moisture regimes. This patchy environment supports a high degree of diversity in vascular plants (1).

Flooding was a common occurrence prior to European settlement. The wide floodplains were covered with water following the spring snowmelt or widespread heavy rainfalls. These wide, nearly flat floodplains held the raising waters, thereby slowing the downstream movement and the height of the crest. Eventually the waters would recede from evaporation, infiltration, and downstream flow. These floodplains, because of the richness of the soil and the value of water as a means of transporting people and goods, have gradually been replaced by agricultural uses and urban development. The flooding, a natural phenomenon, now became a problem. In response, the rivers have had a series of dams constructed, along with other flood protection, and while these have regulated water levels to a degree and altered the normal flooding patterns, flooding still occurs.

Bottomland hardwood forests occur on the floodplains and low-lying terraces along the rivers and larger streams throughout the region. The highly dynamic nature of the river channels prior to the construction of dams had resulted in forests that were dominated by an overstory of cottonwood (*Populus deltoides* Bartr. ex Marsh.) and peach-leaf willow (*Salix amygdaloides* Ander.). Cottonwood is the most ubiquitous overstory species to the northern Great Plains floodplains. Cottonwood, and its most common associate willow, frequent the riverbottom forests. These forests occur on sites frequently inundated by water. Despite the regulation of river flows during this century, this forest type still makes up a significant proportion of the forest land in South Dakota, about 11,000 ha (27,182 ac) (2). The more well-drained transitional sites above support hackberry (*Celtis occidentalis* L.), green ash (*Fraxinus pennsylvanica* Marsh.), box elder (*Acer negundo* L.) and American elm (*Ulmus americana* L.), among other species, with the mesic to somewhat xeric sites along the slopes supporting bur oak (*Quercus macrocarpa* Michx.). The oaks become more scattered near the top of the slopes with the transition to prairie vegetation. Much of the bottomland forests have been significantly altered or eliminated since European settlement occurred. In South Dakota, the average loss rate between 1965 and 1980 was 650 ha (1606 ac) per year (3). This loss is due primarily to conversion to agriculture, not an unusual occurrence. In many areas of the country, the primary factor in the loss of bottomland forests has been agriculture (4). The greatest loss to South Dakota bottomland forests occurred with the construction of dams along the Missouri River between 1935 and 1965. More than 34,000 ha (84,016 ac) of forests were lost to reservoirs. Urban developments and, to a far lesser degree, gravel excavation and navigational structures, have also contributed to the loss of native bottomland forests. There have been some losses of cottonwood forests due to fuelwood harvesting (5).

A less dramatic, but significant, impact on these bottomland forests have been the changes in water flow with the construction of dams. In the absences of flooding, certain species such as cottonwood do not have the proper seedbed conditions (6). The most favorable sites for the establishment of cottonwood are the point bars, as these generally consist of moist mineral soils (7). The timing of the natural floods was also beneficial to cottonwoods and willows, as these trees disperse their seeds in June, a time period where the water levels would be receding. The regulation of water by dams and subsequent reduction in channel migration have resulted in low seedling recruitment of cottonwoods and willows that require fully exposed, moist alluvium for establishment (6). The alteration of the natural flow of these rivers is resulting in a decline of pioneer species such as cottonwood and willow and an increase in later successional species such as green ash (8).

The reduction in fire and the introduction of exotic species have also altered the composition of the bottomland forests. There has been an increase in fire-sensitive eastern red cedar (*Juniperus virginiana* L.) along the floodplains of many rivers. It is regarded as a "weed" by many landowners, and there are efforts currently underway to reduce the occurrence of this species by prescribed fire and harvesting. Russian olive (*Elaeagnus angustifolia* L.) and common buckthorn (*Rhamnus cathartica* L.) have become established in many areas, and there are forests along the Missouri River that are composed of a mature cottonwood overstory with an understory of predominantly Russian olive. The introduction of exotic species has not been limited to trees and shrubs. The spread of Dutch elm disease (*Ophiostoma ulmi*) into the Great Plains has resulted in a significant reduction of American elm from the overstory of bottomland forests.

DAMAGE TO THE BOTTOMLAND FORESTS

Flooding, while a natural and frequent disturbance in the bottomland ecosystem, results in many vegetation changes, including the forests. The intensity and duration of flooding can have a profound effect on the development of bottomland forests. The effects on individual trees are due to the submersion of the trunk and leaves, the burial of the roots and lower trunk with new deposits of soil, mechanical injury to the trunk from ice and floating debris, and chemicals that have become part of the runoff from agricultural fields and sewage released by treatment plants and systems.

The impact of flooding on these forests depends upon the species composition, age, and relative vitality of the trees as well as the season, duration, and depth of flooding. Early season floods, those that occur before the trees break dormancy, are less injurious than those floods that occur after growth begins. Moving floodwater is less harmful than stagnant water. Trees on the low-lying areas away from the riverbanks can be left in standing water as the floodwaters recede, thus greatly increasing the possibility of flood injury (9). The duration of flooding also has a major influence on survival, with relatively few species able to survive more than 30 days of flooding during the growing season.

Flood tolerance varies among species and is dependent upon certain adaptions to anaerobic and hypoxic stresses. Flood-induced morphological and structural changes, including lenticel formation and the development of adventitious roots, permit certain species to survive extended periods of flooding. The species most likely to survive 180 days or more of flooding include box elder, silver maple (*Acer saccharinum* L.), cottonwood, willow (Salix spp.) and American elm (10). However, developing any list of flood-tolerant species is difficult and can only be stated in general terms, as the influence of flooding on trees is still poorly understood.

The extent of injury to the bottomland forest from the 1993-1997 floods is difficult to predict at this time. Many trees are expressing symptoms of flood stress including early fall coloration, reduced leaf size and shoot extension, crown die back and sprouting along the trunks. Flooding may increase susceptibility to secondary organisms, fungi and insects; thus decline and mortality will continue to occur over the next 3 to 5 years. The losses may be greater than expected. While forests are native to these bottomlands, the composition of these forests has changed since settlement. The regulation of water flow and fire protection has allowed green ash, eastern red cedar and other species to colonize the river banks. The flooding will have a great effect on these less flood-tolerant species.

An additional area of concern is for the trees that were planted or established behind levees or along regulated waterways. The flooding of the James River in 1995 and 1997, which spilled over the levees near Huron, South Dakota, resulted in the mortality of the eastern red cedars that were planted along the river. The urban forests in many of the flooded communities are composed of species not common to floodplains, thus poorly adapted to survive the flooding. Additional losses are expected in these areas.

DAMAGE TO THE BOTTOMLAND FOREST FROM FLOOD MITIGATION PROGRAMS

The property and agricultural losses to flooding have run into the billions of dollars. This despite the fact that many levees and other structural restraints have been built over the past century. It has been suggested that the construction of these restraints may even have contributed to flooding by their channeling and encouraging development on the floodplains (11). However, in the most recent flooding in the northern Great Plains, most of the levees held and most failures were attributed to their being too low. Communities along the major rivers are already beginning plans for the next flood by proposing higher levees and other flood protection structures.

The proposed solution to the flooding experienced in the region includes excavation, drainage, and creating retaining structures. One recommended mitigation practice is to harvest trees along the banks and replace them with grasses. This suggestion is based upon the idea that trees along banks increase erosion potential. Removal of the large trees is considered to be particularly important, as these may fail in the saturated soil condition, fall, and create snags. While these snags can retard water flow, this woody debris is considered beneficial to fish. The removal of dead trees is also considered to be a solution to reduce the extent of flooding. The benefits of eliminating riverbank forests as a flood control measure are not well documented. The further loss of the native bottomland forests as a flood mitigation measure should be strongly discouraged until more data are collected on the effects of such action.

RESTORATION OF THE BOTTOMLAND FORESTS

The restoration of forests are a much more long term project than most other types of restoration. Restoration involves the creation of an ecosystem with the same structure and composition that occurred prior to the disturbance. Rehabilitation is the creation of an ecosystem that is similar. Replacement/reallocation is a replacement of the ecosystem with another. Though generally referred to as restoration, most project more closely fit rehabilitation or replacement/ reallocation. However, the term restoration has been used as a general reference to any type of work and will be used as such in this discussion.

Restoration projects on former agricultural land involve either planting or natural dispersal and generally include both means of revegetation. A common practice is planting either by seed, cuttings or seedling, a few species and relying upon natural dispersal to further colonize the site (12). Many projects plant trees in rows out of necessity, to conform to the equipment needs in planting and post-planting weed control. There is also value in planting species in recognizable and appropriate association, if only from an aesthetic standpoint.

A simpler means of restoring bottomland species is to create bare, moist soils and rely upon natural seedfall (13). The sites should not be the low riverbank scour-prone areas as these spots may experience significant seedling and sapling mortality during floods (14). However, if the seed bed is properly prepared and these activities synchronized with seed dispersal from nearby native trees, the use of natural seedfall can result in good establishment.

It is also important to consider the long-term implications of attempting to restore forests to a pre-European settlement composition. The unstated reference point for many projects is prior to European settlement. These forests may not be sustainable or follow a predictable pattern due to the cessation of flooding and other alterations of natural floodplain processes (15). Thus, the restoration of bottomland forests will require more than planting or seeding. The issue of water regulation will have to be addressed. The long-term sustainability of these bottomland forests is dependent upon the formation of point bars and the erosion of the adjacent banks. Prescribed flow releases from dams are a means of creating such sites. However, the widespread acceptance and use of such measures will require much cooperation and coordination among stakeholders (6). Strategies such as prescribed flow releases will require much additional research.

IMPLICATIONS FOR RESTORATION PROJECTS

Ecological restoration, the practice of restoring and managing ecosystems, is a relatively new field. The composition, structure, and dynamics of these bottomland systems are not adequately understood. In addition, the outcome of anyone restoration project is nearly impossible to predict because of the differences in planting stock, management, and environmental conditions among the different projects. There have been few opportunities to study the long-term development of these managed systems. Restoration efforts have in many instances been governed by trial and error. Ironically, a need now exists to provide answers to questions regarding the feasibility or procedures for such projects, but the long-term data do not exist to adequately address managers' concerns. What is needed is the development of a database from these projects. There are many questions that need to be answered. While a "recipe book" is not necessary and should probably be discouraged, there is a need for more practical guidelines.

REFERENCES

1. Keammer, W. R., Johnson, W. C., and Burgess, R. L. (1975) Floristic analysis of the Missouri River bottomland forests in North Dakota. Canadian Field Naturalist 89(1): 15–19.
2. Collins, D. C., and Green, A. W. (1988) South Dakota's timber resources. USDA For. Serv. Res. Bull. INT-56.
3. Raile, G. K. (1984) Eastern South Dakota forest statistics, 1980. USDA For. Serv. Res. Bull. NC-74.
4. U.S. Department of the Interior (1988) The impact of federal programs on wetlands. Vol. 1. The lower Mississippi alluvial plain and the prairie pothole region. A Report to the U.S. Congress by the Secretary of the Interior, Washington, D.C.
5. May, D. M. (1996) Residential fuelwood consumption and production in South Dakota. USDA For. Serv. Res. Bull. NC-171.
6. Johnson, W. C. (1992) Dams and riparian forests: case study from the Upper Missouri River. River 3: 229-242.
7. Noble, M. G. (1979) The origin of *Populus deltoides* and *Salix interior* zones on point bars along the Minnesota River. The American Midland Naturalist 192(1): 59–67.
8. Johnson, W. C., Burgess R. L., and Keammer, W. R. (1976) Forest overstory vegetation and environment on

the Missouri River floodplain in North Dakota. Ecol. Monogr. 46: 59–84.

9. Kozlowski, T. T. (1984) Plant responses to flooding of soil. BioScience 34: 162–167.

10. Whitlow, T. H., and Harris, R. W. (1979) Flood tolerance in plants: a state-of-the-art review. Vicksburg, MS: U.S. Army Engineer Waterway Exp. Sta. Tech. Report E-79-2.

11. Hey, D. L., and Philippi, N. S. (1995) Flood reduction through wetland restoration: the Upper Mississippi River basin as a case study. Restoration Ecology 3: 4–17.

12. Newling, C. J. (1990) Restoration of bottomland hardwood forests in the lower Mississippi Valley. Restoration and Management Notes 8(1): 23–28.

13. Friedman, J. M., Scott, M. L., and Lewis, W. M. Jr. (1995) Restoration of riparian forest using irrigation, artificial disturbance, and natural seedfall. Environmental Management 19: 547–557.

14. Asplund, K. K., and Gooch, M. T. (1900) Geomorphology and the distributional ecology of Fremont cottonwood (*Populus fremontii*) in a desert riparian canyon. Desert Plants 9: 17–27.

15. Shear, T. H., Lent, T. J., and Fraver, S. (1996) Comparison of restored and mature bottomland hardwood forests of southwestern Kentucky. Restoration Ecology 4:111–123.

THE HARD PATH AND THE SOFT PATH TO FLOOD PROTECTION

Dexter Perkins
Department of Geology and Geological Engineering
University of North Dakota, Grand Forks, ND 58202

INTRODUCTION

More than two decades ago, Amory Lovins talked about the "hard path" and the "soft path" to energy security for the United States. The cost of energy was increasing, U.S. reserves were declining, the reliability of imports was decreasing, and demand continued to increase. "Hard path" solutions to our energy problems were more of the same: more exploration for fossil fuels, more nuclear reactors, bigger generating facilities, relying on high tech, great expense and, according to Lovins, an insecure future. "Soft path" solutions included conservation, alternative energy sources, local power supplies, less expense, and more long term security.

In 1879, the first major flood control levee project began in the United States when the Mississippi River Commission began building levees along the lower Mississippi; 3 years later those levees were breached in 284 places. By 1926 the Commission had built over 1800 mi (2900 km) of levees, most over 20 ft (6 m) high; in 1927 they were breached in 225 places, flooding 20,000 mi² (52,000 km²). Major construction and river modification occurred for the next 45 years, but floods continued. In 1973, dikes were topped in many places as the river flooded in ten states, reaching record flood heights. Despite continued flood control projects by the U.S. Army Corps of Engineers and others, 1993 saw still a larger flood, the largest flood since measurements began. Nine states were federal disaster areas, 75 towns were destroyed, and total damages exceeded $20 billion (16).

Today, in North Dakota, Minnesota, and elsewhere we face flood threats and must find solutions to our flooding problems. Hard path solutions might include more dams, dikes, levees, or diversions—traditional and increasingly expensive solutions to flooding in the past. The Army Corps of Engineers and others are poised with their bulldozers waiting, but despite the billions spent on hard path flood control, flood damages continue to rise in the United States. The National Council on Public Works Improvement found that the Corps of Engineers and the Soil Conservation Service spend between $2 billion and $3 billion on flood control programs each year (1). Yet flood damages continue to increase, and today average about $8 billion per year (2). During the last two years, the Federal Flood Insurance Fund has borrowed $450 million from the Treasury to keep up with increasing claims. According to the Federal Reserve Bank, taxpayers will pay more than $1.75 billion in direct costs for the 1997 Red River Flood. Red River Valley residents will suffer an additional economic cost of at least $2 billion. Clearly, the hard path is not giving us the kind of flood protection we want. And given the recent fiscal trends in Washington, it seems unlikely that funding for hard path solutions will continue to be easily available.

Flood control structures are expensive and, perhaps worse, give citizens a false sense of security (3). In 1995, the Army Corp reported that flood control structures encourage sprawl and floodplain building. They decrease the frequency of floods while increasing significantly their severity. Nearly every major flood in U.S. history has occurred in areas with substantial amounts of diking or channelization. More than 200 flood control dams can be found in the Red River Basin, yet the 1997 floods still occurred (4). Before building more dikes and diversions, local and other government agencies seeking additional flood protection should first consider whether soft path measures are more appropriate—there is no doubt they are less expensive. The two most effective soft path solutions are relocating out of a flood-prone area and developing basinwide flood control plans that focus on stopping or slowing water in wetlands before they reach major rivers.

FLOODPLAIN PROBLEMS

In central North Dakota, Devils lake has doubled in size since 1993. Lake level has risen 18 ft (5.5 m) and water threatens many buildings and roads. Many North Dakotans have argued emotionally for a hard path solution: build a drain to the Sheyenne River. President Clinton authorized $50 million for the project, but in April the House removed the money (5). In a 1996 report, the Army Corps reported that an egress will not solve the flooding problems. According to the Corps, the most effective outlet they can design without causing too many problems elsewhere would only move the equivalent of 0.5-1 ft (0.15-0.3 m) of water per year from the lake—a lake that has risen 18 ft (5.5 m) since 1993. Yet, supporters of an outlet ignore the Corps calculations and continue to promote an outlet as the solution to their problems. The soft path alternative is to relocate people, buildings, and other infrastructure. Relocation has begun and will continue. Still, the real problem is that we allowed building in the Devils Lake floodplain. A hundred years ago, lake levels were close to what they are today, but between then and now the lake was much lower and building took place in the floodplain. If planners and builders had been more perspicacious, they would not have built in flood-prone areas in the first place. Thus, sound land use plans are perhaps the best sort of flood protection we can develop.

> "Floodplains are for floods."
> The Australian Minister for Environment and Conservation, 1974 (17)

The public and some policy makers are slowly becoming aware that levees and flood control works do not guarantee safety in floodplains. Absence does. After the 1997 flood, Mayor Pat Owens of Grand Forks said, "There will be some areas that won't rebuild. I see a downtown with not so many buildings, but a park area with more green space where people can gather and enjoy the river" (6). In Rapid City, South Dakota, after the devastating 1972 flood, federal flood relief funds were used to buy more than 1400 homes and businesses and to establish a park, golf course, and greenway in flood-prone areas (7). In St. Charles County, Missouri, more than 10,000 homes and businesses were similarly moved after the 1993 floods, and the entire town of Valmeyer, Illinois, was moved to higher ground the following year (8). Grand Forks, Rapid City, St. Charles County, and Valmeyer have all come to the conclusion that flood protection, to varying degrees, must come from soft path solutions.

WHY WATERSHED PLANS ARE NEEDED

One lesson from the 1993 Mississippi River floods was that hard path solutions to flooding generally create problems for those downstream (9). In the Red River Valley, this dilemma has arisen many times. The city of Breckenridge protested efforts by the upstream community of Wahpeton to raise their levees. The same problem has come up on the North Dakota-Minnesota border, resulting in a court decision requiring mandatory lowering of levees on both sides of the Red River. If acted on, recent proposals for further dike building and a possible river diversion in and around Grand Forks will add to flooding problems for those to the North. While it seems clear that flood protection plans must involve more than just local planning, hard path projects are nearly always local.

WETLANDS: A SOFT PATH SOLUTION

When asked about upland water storage to protect towns near Devils Lake, North Dakota, the North Dakota State Engineer noted that the upper basin wetlands had the potential to store 200-300 million acre-feet (247-370 billion m^3) of water. He concluded that "substantial restorable storage exists within the Devils Lake Basin" (3). Wetlands, such as those in the Devils Lake Basin, serve two vital purposes during flood times—they hold water and they slow the flow of water into streams and riverways.

> "A presidential panel appointed after the 1993 flood estimated that a wetlands-restoration strategy could reduce runoff by 12 to 18 percent . . ."
> Minneapolis Star Tribune Editorial, April 18, 1997 (18)

The flatter the land, the more effective wetlands are for flood protection. So, the Red River Valley and other broad river valleys are ideal places for natural and restored wetlands to provide flood protection. Without wetlands, water runs rapidly toward the Red River. Draining wetlands for row crops increases runoff rate by 200 to 400% over natural conditions and may decrease the time from the beginning of flood stage to peak by more than 60% (9). Undrained wetlands store and slow water, thus reducing maximum flood stages and spreading floods over longer times—keys to flood protection in river valleys. In flat river valleys, only a small decrease in maximum flood stage can save thousands of acres from flooding. This can be accomplished without pushing floodwaters onto someone else.

The 1993 Mississippi River floods clearly highlighted the importance of wetlands for flood protection. The states with the worst flooding (Missouri, Illinois, and Iowa) were also those that had destroyed the most wetlands. In 1994, the Interagency Flood Plain Review Committee (IFPRC) concluded that "where significant wetlands exist, they can have a noticeable effect on (flood) discharge peaks from the basin" (10). In a 1995 article in Restoration Ecology, Hey pointed out that, "despite the nation's massive effort during the past 90 years to build levees throughout the upper Mississippi Basin, mean annual flood damage has increased 140 percent during that time. . . . By strategically placing wetlands on hydric soils in the Basin, we can solve the Basin's flooding problems in an ecologically sound manner" (11).

> "By strategically placing wetlands on . . . soils in the [upper Mississippi] Basin, we can solve the Basin's flooding problems . . . "
> Hey, 1997 (11)

Although detailed studies have not been conducted in the Red River Valley, in Minnesota, the IFPRC determined that wetland restoration on the Redwood River could easily decrease 100-year flood peaks by 10%. The Redwood River Valley is similar to the Red River Valley, being wide, having a low gradient and containing many drained potholes. In Iowa, the IFPRC estimated that the Conservation Reserve Program, the Small Wetlands Acquisition Program (SWAP) and other measure could reduce 100-year flood peaks by up to

40%. Either a 10% or 40% reduction would have been sufficient to lower the 1997 Red River flood to below the levees in Grand Forks (3).

THE SITUATION IN THE RED RIVER VALLEY

The Red River Valley and its borderlands were once known for their spectacular wetlands. Today they are not. Some Minnesota counties, such as Wilkin, Traverse, and Grant, have drained more than 99% of their wetlands for agriculture. In North Dakota, Pembina, Grand Forks, Traill, Cass, and Richland Counties have lost over 90% of their wetlands. According to a University of Minnesota study, 79% of the wetlands in the Minnesota Red River Valley and 63% of the wetlands in the North Dakota Red River Valley have been destroyed. This totals to more than 14,000 mi^2 (36,000 km^2), equivalent to 9 million acres, and capable of holding more than 27.5 million acre-ft (33,900 million m^3) of water (3).

Skeptics argue that the water that Red River Valley wetlands could hold is insignificant, but that is not true; 27.5 million acre-ft (33,900 million m^3) is equivalent to more than 150 days of the peak flood flow past Grand Forks in 1997. In other words, during peak flood flow, 91,000 cfs (8,500 m^3/sec) passed through Grand Forks. This water could be held by 60,000 acres of wetlands (equivalent to 94 mi^2) per day. This is less than 0.5% of the total area of the Red River Valley (3).

Because peak flood flows only last a few days and because storing all the flood water is not necessary, restoring only 5-10% of the Red River Valley wetlands could stop devastating floods. Similar calculations made after the Mississippi River floods of 1993 suggested that restoring 7% of the Mississippi River wetlands would give adequate flood protection (11). A recent study by the Competitive Enterprise Institute showed that wetland restoration programs like the North American Waterfowl Management Plan are cost effective, costing around $210 per acre for purchase and restoration of wetlands in the northern Great Plains (12). Other programs, including the Conservation Reserve Program, may have higher price tags. Current studies suggest that if we invoke wetlands acquisition and restoration/easement programs for flood protection in the Red River Valley, the maximum cost would be $10 million for each of the peak flood days—much less than the billions of dollars' destruction in 1997.

> "Restoring wetlands in this area is often a difficult process because most farmers out here consider water the enemy . . . "
> Moore, 1997 (19)

POLITICAL AND LEGAL PROBLEMS

Unfortunately, local, state, and federal government programs continue to support wetland destruction. Interior Secretary Babbitt recently identified more than 40 federal programs that encourage wetlands destruction and promote building in flood plains (13). Thirty years ago, in the Report of the Task Force on Federal Flood Control Policy, White pointed out that much floodplain encroachment and wetland destruction takes place "because it is profitable for private owners even though it imposes heavy burdens on society" (14). The situation has not improved today.

Federal Programs designed to protect wetlands have been ineffective in North Dakota and Minnesota. Between 1992 and 1997, landowners offered the U.S. Fish and Wildlife Service 172 tracts of land in North Dakota under its Small Wetland Acquisition Program (SWAP) (3). Although all tracts met the SWAP criteria, only 15% of the sales were completed—the North Dakota Governor or County Commissions blocked the others. These lands could have provided flood protection, wildlife habitat, hunting lands, and greenways but, because of North Dakota's traditional antiwetland politics, continue to function as marginal or fallow farm lands instead. As part of a compromise with wildlife and hunting groups, North Dakota enacted a No Net Loss Wetlands Law in 1986. It was never effectively implemented, and the North Dakota Legislature repealed it less than a decade later because of antienvironmental politics.

In the lower 48 states, about half of all wetlands have been destroyed. Federal programs, such as the Clean Water Act (CWA), are supposed to protect those that remain. Under the CWA, projects involving no wetland destruction are, in principle, most easily permitted. If destruction is unavoidable, it must be minimized and mitigated (3). Section 404, which requires permits to fill wetlands, is the most significant and controversial part of the act. However, it is not well enforced. Although the act requires wetland protection, in 1995, over 99% of the wetland destruction permits requested were approved. In North Dakota, 98% of all permits were approved between 1988 and 1996—they are generally approved unless some significant public opposition is present (15). So, even if a few draining projects are stopped, others go forward without opposition. In Grand Forks County, plans to drain sections of the Upper Turtle River watershed arise every few years. Eventually, vigilant farmers and wildlife enthusiasts will forget to oppose them and permits will be granted.

Besides Section 404 permits, the Army Corps of Engineers also gives wetlands destruction permits through the Nationwide Permit System (NWP) (3). Of the various kinds of NWP permits, two are most significant in considering flood control. NWP 26 allows for building on isolated wetlands of less than 10 acres (0.4 km^2)—effectively including most wetlands in the prairie pothole region. The Clinton Administration has proposed lowering this threshold to 3 acres (0.1 km^2). Ten acre (0.4 km^2) and smaller isolated wetlands are critical in states such as North Dakota and Minnesota where most wetlands have already been drained. NWP 29 allows homes to be built on wetlands of less than one-half acre (2000 m²). Because few homes exceed 40,000 ft² (3700 m²), this program effectively allows any house to be built on small wetlands. Usually, draining and road building, etc., mean the effect of the house building is felt on much more than the half-acre (2000 m²) lot.

Developers argue that mitigation required by the 404 or other programs can compensate for wetland destruction. Sometimes and in some ways it can. Still, removing wetlands from floodplains and flood-prone areas and replacing them elsewhere does not provide the same degree of flood protection. Additionally, many mitigation projects are really just restoration projects, so wetland loss continues.

> Normal flood frequency curves no longer apply to the Red River Valley. There is every reason to expect more severe floods during the next decade. The flood of 1997 was not a random event. It was caused primarily by climate change. Our inability to handle it, however, relates to urbanization, agricultural practices, and unwise land use. None of these factors will change in the near future; things may become worse. We may see more precipitation; we will see more urbanization; agricultural practices are unlikely to change; and land use restrictions will be fought by many.

WHAT TO DO?

While soft paths to flood protection make good sense, following them is difficult. Vested interests of all sorts often find profit in maintaining the same ineffectual strategies. Making sound local decisions always means that apparent winners and losers are nearby. For dikes and other engineering projects, the "winners" generally outnumber the "losers"—particularly because the federal government pays for most of such projects. For soft path solutions, the "losers"—or at least the vociferous ones—often outnumber the "winners". People asked to give up their properties, even if compensated, often become outraged. Farmers asked to have restored wetlands on their properties, even if paid, are resistant. Because inertia is the norm, it is tempting to rely on policy changes at the state or national level, changes that are not taking place.

In the future, we can expect to have more floods and we can expect little help from Washington or the State House. Even during nonflood periods, state legislatures are political quagmires, and rural legislators dominate rural states. In such states, which are the ones with the most wetlands, movement away from traditional approaches to flood control is difficult and unlikely. In Washington, recent congressional reforms involving wetlands have gone in the wrong direction. Political action committees associated with companies that profit from making it easier to destroy wetlands have given more than $25 million to members of Congress and presidential candidates since 1990 (3). The recent conservative revolution is toward more local and less federal government programs, and any restrictions on land use are extremely unpopular. We are going to have to develop local solutions to flood problems, or we are going to have to live with increased flood risks and their consequences. And if we are to develop local solutions, we will be practically and financially best served if we concentrate on the soft path rather than following a path that has led to disasters in the past.

REFERENCES

1. National Council on Public Works Improvement. (1988) Report to the President and Congress.
2. Devine, R. (1995) The trouble with dams: environmental problems, high cost of operation. The Atlantic Monthly, August.
3. Hulsey, B. (1997) Red River Rampage: How restoring wetlands and moving homes from floodplains can reduce future flood risk. The Sierra Club and Clean Water Network.
4. United States Army Corps of Engineers. (1995) Floodplain Management Assessment. U.S. Corps of Enginneers.
5. Brasher, P. (1997) Chances for getting money for Devils Lake outlet dim. Associated Press, April.
6. Haga, C. (1997) Next time stronger. Minneapolis Star Tribune, May 27.
7. Rebuffoni, D. (1997) How other cities keep flood water at bay. Minneapolis Star Tribune, April 27.
8. USA Today editorial. (1997) Taxpayers losing battle. April 1.
9. Science Assessment and Strategy Team (SAST). (1994) A blueprint for change, Part V, Science for floodplain management into the 21st century. Interagency Flood Plain Review Committee.
10. Tolman, J. (1997) Swamped. Competitive Enterprise Institute, April.
11. Hey, D. (1995) Flood reduction through wetland restoration: The Upper Mississippi River Basin as a case history. Restoration Ecology, March.
12. Tolson, J. (1997) Swamped. Competitive EnterpriseInstitute, April.
13. United States Department of the Interior News Release. (1994) Interior Department report recommends revisions in Federal programs detrimental to wetlands, July.
14. White, G. (1966) Report of the Task Force on Federal Flood Control Policy. U.S. Congress.
15. Environmental Working Group. (1996) www.ewg.org.
16. Abbot, P. (1996) Natural Disasters. Dubugre, W.C. Brown.
17. Murck, B., Skinner, B., Porter, S. (1997) Dangerous Earth. New York, Wiley Interscience.
18. Editorial. (1997) Minneapolis Star Tribune, April 18.
19. Rebuffoni, D. (1997) Retiring land could help control future damage. Minneapolis Star Tribune, May 6.

PREVENTING AND RESOLVING DISPUTES: THE INTERNATIONAL JOINT COMMISSION'S ROLE UNDER THE BOUNDARY WATERS TREATY

Frank Bevacqua
International Joint Commission
1250 23rd Street NW, Suite 100, Washington, DC 20440

ESTABLISHMENT OF BINATIONAL REGIME

While much current effort focuses on defining the rights and responsibilities of nations regarding the shared environment, one regime between Canada and the United States has had a record of success spanning more than 85 years. The Boundary Waters Treaty of 1909 has provided a framework for the two countries to consider water quantity issues on a watershed basis, cooperatively develop water resources, restore or maintain water quality in various watersheds, and address air quality concerns along the boundary. Activities under the treaty include ongoing binational monitoring of water quality in the Red River Basin and, most recently, a binational investigation to examine issues related to flooding in the Red River Basin.

The purpose of the treaty is:

> ... to prevent disputes regarding the use of boundary waters and to settle all questions which are now pending between the United States and the Dominion of Canada involving the rights, obligations or interests of either in relation to the other or to the inhabitants of the other, along their common frontier, and to make provision for the adjustment and settlement of all such questions as may hereafter arise ...

To accomplish this purpose, the treaty established a set of principles for sharing water resources and mechanisms for addressing issues that might arise. Safeguards to protect the sovereign interests of both countries were included as an integral part of both the principles and mechanisms. One mechanism is the International Joint Commission, an institution that may be used, when both parties choose, for independent fact-finding or decision making.

The commission, consisting of three members appointed by the President of the United States with the consent of the U.S. Senate and three appointed by the Government of Canada, met for the first time in 1912. The independence of the commission's mission is reflected in the oath of office taken by commissioners, who affirm they will faithfully and impartially carry out the responsibilities assigned to them in the Boundary Waters Treaty. In contrast to bilateral processes that bring together national delegates representing the positions of their governments, the commissioners act as a single body seeking common solutions in the best interests of both nations and their shared resources.

The treaty gives the commission authority to approve certain uses, obstructions, or diversions of waters along the boundary and to investigate and report on questions of mutual concern when requested by the governments. Commissioners are assisted in these activities by over 20 binational boards and task forces, as well as a small staff in its offices at Washington, D.C., and Ottawa and Windsor, Ontario. In addition, the treaty states that questions or matters of difference may be referred to the commission for binding decision when both parties consent, but the commission has never been requested to exercise this authority.

APPROVING WATER USES ALONG THE BOUNDARY

The Boundary Waters Treaty addresses the use of both boundary waters and waters crossing the boundary. Boundary waters are defined as the lakes, rivers, and connecting waterways along which the international boundary between the United States and Canada passes, including all bays, arms, and inlets, but not including tributary waters.

Under the treaty, the upstream country retains exclusive jurisdiction and control over the use and diversion of all waters originating on its side that, in their natural channels, would flow across the boundary or into boundary waters. However, should any interference or diversion of such waters result in injury on the other side of the boundary, the injured party is entitled to the same legal remedies as if the injury took place in the country where the interference or diversion occurs. The practical effect of this mechanism would give an injured party access to the court system in the country where the interference or diversion took place, though the commission is not aware of any such cases having ever been filed.

In cases involving the boundary waters themselves, no uses, obstructions, or diversions of boundary waters that affect the natural level or flow on the other side shall be made unless approved by the Governments of the United States and Canada within their respective jurisdictions and by the International Joint Commission. If the two governments do not wish to give jurisdiction to the commission, however, they reserve the prerogative to permit such uses, obstructions, or diversions by directly negotiating a special agreement. The treaty also expressly states that these provisions do not limit the existing rights of either government to deepen channels and construct works on its side of the boundary for the benefit of commerce and navigation.

When a dam or other project in the downstream country would raise the natural level on the other side of the boundary in a river flowing across the boundary or in waters flowing from boundary waters, commission approval or a special agreement between the governments is required.

Applications for more than 60 projects or project modifications have come before the commission. The geographic range of these projects extends from the St. Croix River on the Maine–New Brunswick border to the Skagit River that flows from British Columbia into the state of Washington. The purposes for their construction include hydroelectric power generation, flood control, navigation, and irrigation. Applications for projects undertaken by the federal governments come directly to the commission, whereas applications by others come to the commission through the federal government in whose jurisdiction the project will be located.

In reviewing applications, the commission's role is to ensure that affected interests across the boundary from the proposed project are adequately considered in a manner consistent with rules set out in the treaty. The commission may retain the authority to regulate the flow of water through projects it has approved. In such cases, it appoints a board of control, with an equal number of members from the United States and Canada, to ensure that operations remain in compliance with the conditions of the commission's orders of approval. Board members serve in their personal and professional capacity and not as representatives of the geographic regions where they live or the organizations where they work. In addition, an organization is in no way committed by positions taken by one of its employees when that person is serving on a commission board.

INVESTIGATING ISSUES OF MUTUAL CONCERN

The commission is empowered to investigate and report on any question or matter of difference referred to it by the governments under Article IX of the Boundary Waters Treaty. Recommendations provided by the commission in its reports to governments are nonbinding and, according to Article IX, shall in no way have the character of an arbitral award. Nonetheless, recommendations arrived at through the binational fact-finding and consensus process can carry substantial weight and have helped the governments resolve a number of difficult issues.

Though the treaty states that either government may request that questions be referred to the commission, all such "references" have taken the form of joint terms of reference from the two governments. As a practical matter, the commission's capacity for joint fact-finding would be severely limited if only one country supported an investigation.

Technical investigations are conducted by commission-appointed study boards or task forces with an equal number of members from the United States and Canada. Members may come from federal, state, and provincial agencies, as well as universities, industry, environmental organizations and other entities with the appropriate expertise. As with commission boards of control, members serve in their personal and professional capacity. Various forms of public consultation and involvement, such as public meetings, site visits, roundtable discussions, and citizen study participants, have played a prominent role in commission investigations, and formal public hearings are held before the commission prepares its final report to governments.

More than 50 matters have been referred to the commission for investigation, nearly all of which have involved transboundary water quantity, water quality, or air quality issues. An investigation initiated in 1944 provided the basis for the two countries to coordinate and share the benefits from developing hydropower in the Columbia River system. Another that began in 1952 proposed flood control benefits that were then agreed upon by the governments when the St. Lawrence Seaway and international hydropower project were built. Commission conclusions and recommendations enabled the governments to avert substantial transboundary impacts to fisheries and other resources from the Garrison Diversion Project in the upper Missouri River Basin in North Dakota and from a proposed coal mine on the North Fork of Flathead River in British Columbia.

One of the more remarkable principles established by the Boundary Waters Treaty is that boundary waters and waters flowing across the boundary shall not be polluted on either side to the injury of health or property on the other. A number of references to the commission have helped the governments to interpret and uphold this principle and have resulted in ongoing monitoring activities. For example, the commission, with the assistance of its boards, monitors compliance with binationally developed water quality objectives in the Red River Basin and has overseen efforts to restore the salmon fishery in the St. Croix River Basin along the border between Maine and New Brunswick.

One of the commission's investigations provided the basis for the 1972 Great Lakes Water Quality Agreement, which was directed toward controlling sewage, oil, debris, and other conventional pollutants. Under the agreement, the governments gave the commission an ongoing reference to assess their progress toward achieving the agreement's goals. Standing advisory boards and the commission's Great Lakes Regional Office in Windsor, Ontario, were established under the agreement, which has become a major focus of commission work. The commission issues a comprehensive report on progress under the agreement every 2 years. A new agreement was signed in 1978 that included a greater focus on eliminating the discharge of toxic substances and committed the governments to taking an ecosystem approach.

The first reference on air quality came in 1928 when the governments asked the commission to assess the transboundary impacts of emissions from a smelter at Trail, British Columbia. The landmark case set the legal precedent that while a country has the prerogative to use its resources within its boundaries as it sees fit, it also has the responsibility to assure that environmental damage not occur in another country. The commission maintains an alerting function for transboundary air quality issues along the international boundary resulting from a reference on air pollution in the Detroit, Michigan–Windsor, Ontario, region. The 1991 Air Quality Agreement also asks the commission to seek public comment on bilateral progress reports.

RED RIVER FLOODING INVESTIGATION

In June 1997, following a flood that greatly exceeded all records, the governments asked the commission to examine and report on the causes and effects of damaging floods in the Red River Basin and to make recommendations on means to reduce, mitigate, and prevent harm from future flooding. To assist with its responsibilities under this Article IX reference, the commission has appointed a binational task force with a codirector from each country to examine a range of issues and management options consistent with the terms of the reference. The governments requested an interim report by the end of 1997 identifying measures that could be implemented in the near term and a final report by the end of 1998.

For the full text of the Red River flooding reference, the Boundary Waters Treaty, and the Great Lakes Water Quality Agreement, as well as other information about the work of the commission, visit the commission's site on the World Wide Web at www.ijc.org(.)

THE EVER PRESENT CHANCE OF FLOODING

Joseph H. Hartman
Energy & Environmental Research Center, University of North Dakota
15 North 23rd Street, Grand Forks, North Dakota 58203

INTRODUCTION

There is a singular consensus that flooding is as inevitable as death, taxes, and cold North Dakota winters. The extremely low gradient of the Red River of the North and the nearly flat surface of the bed of glacial Lake Agassiz produces a broad floodplain perfect for widespread flooding (1, 2, 3). Efforts to mitigate the effects of flooding on human inhabitants living near rivers seem, geologically speaking, unlikely to succeed in the long term without a better understanding of the costs and benefits of abatement features in regard to natural riparian systems and climate cycles. Without such information, heavy winter snows, rapid spring melts, and flash rainstorms are destined to occur and raise havoc with the best-laid protection plans.

As devastating as "record" floods are to the well-being of communities living in broad floodplains, towns of any size only infrequently pick up and resettle out of harm's way. Thus well-thought-out contingency plans are required to produce the year-to-year stability most residents desire. It seems clear, however, that even year-to-year strategies are too short-term to cope with natural disasters, which are, after all, disasters only to us, not to nature. Contributors to the symposium on the River Red flood of 1997 (4) are sending unequivocal messages about the need for long-term, generation-to-generation planning including nature-based responses to natural occurrences.

FLOODING AND CLIMATE

An understanding of the pattern of flooding over a long period of time is important to assessing the necessary scale of flood abatement procedures to protect the greatest number of citizens possible. Flood data since the late 1800s suggest an increasing trend toward the greater frequency of large-scale flooding since the 1950s (5). Bluemle (1) suggests that the development of established communities along the Red River occurred during relatively drier conditions. The intermittent occurrence of moderate flooding events has been insufficient to dissuade developers and future homeowners from building adjacent to the river within known flooding corridors. The almost regular occurrence of significant floods since 1965 has not diminished expansion of cities into flood-prone areas.

The recurrence interval of flooding is not predictable from one year to the next. Compounding weather events make flood forecasting difficult at best (6), but an understanding of fall precipitation, snow accumulation, and soil conditions, along with the physical parameters of the river basin, provide a basis for modeling potentially extreme conditions. Interpreting short-term climate trends, however variable from one year to the next, will contribute to an understanding of flood frequency or potential flood severity.

Temperature, precipitation, and other biosphere phenomena have changed continuously throughout the earth's geologic history. An example close to home is that the area of Grand Forks–East Grand Forks was covered by as much as 100 m (330 ft) of water 10,900 years ago (6, 7). Climate cycles, trends, or events of various durations and magnitudes have since occurred, requiring cultures to respond successfully or perish. Even since the last glaciation, small temperature changes (probably less than 2°C) have resulted in notable changes in precipitation patterns (9) and locations of human occupation. The greatest (worst) flooding of the Red River occurred in the middle 1820s (5, 10) with crests reaching heights possibly significantly greater than that attained by the flood of 1997. Ongoing climate studies (e.g., 11) suggest that short-term climate cycles may influence the frequency of flood events. Understanding climate trends or cycles, as well as interpreting the cause and effects of past climate change is, and undoubtedly will remain, a major subject of thought in the scientific community. Recognizing climate change in earth's history is no longer only an academic pursuit; El Ninõ events, global warming, ozone variability, and the wide range of human influences on the environment and vice versa are now of fundamental concern to a significant portion of the population.

NATURAL FLOOD ABATEMENT

As devastating floods will challenge the best-constructed abatement features (1, 12), what other options are available to reduce the effects of record flooding on a community? The emphasis of natural abatement methods is to reduce the amount of water entering the river system when the flow rate and volume in the main channel are already high because of the spring thaw. Both riparian and wetland areas, along with other related mitigation activities (2, 13), are significant snow/water catchment areas that can reduce crest flow at critical times. The "soft path" or natural solution reviewed by Perkins (12) concerns the restoration of wetlands but may equally apply to maintenance of riverine forests: "The flatter the land, the more effective wetlands are for flood protection. So, the Red River Valley and other broad river valleys are ideal places for natural and restored wetlands to provide flood protection." Thus it would seem logical that a generational response to the consequences of severe flooding should include ecologically sound river management along with effective abatement plans.

SUMMARY

The 1997 flood of the Red River of the North was a wakeup call. The disastrous effects on the citizens of Grand Forks and East Grand Forks should not be understated, but it could have been worse. Planning for a stable future for these and other towns along the Red River requires attention to detail from both the public and professional communities. As examples of community involvement and planning, the response to the devastating floods that occurred through Rapid City in 1972 and to the majority of the counties in Arizona in 1993 was to establish policies based on long-term thinking. Rapid City established a green corridor in the most flood-prone areas. Arizona's state and federal response was to link agencies actively involved in flood-related data gathering to support open communication for both data and interpretations (13). Although the spring events associated with the severe flooding of the Red River are different than in these examples, the resulting efforts to minimize flooding effects through careful planning may serve as role models. Understanding the record of flooding through the interpretation of historic data (of which Grand Forks has as much as most gaging stations) has proved insufficient to instill a proactive perspective on preparation for major flood events. To promote greater appreciation for the river's history, studies should be considered that interpret flooding events preserved in Holocene sediments of the recent past to investigate the possibility of long-term cycles of flooding. The specific importance of wetland and riparian maintenance and restoration should be reevaluated with respect to the long-term benefits of a comprehensive policy on Red River water management.

REFERENCES

1. Bluemle, J.P. (1997) Factors affecting flooding in the Red River Valley. North Dakota Academy of Science (NDAS) Proceedings 51 (Supplement 1), this volume.
2. Ball, J.J. (1997) Restoration of bottomland forests – Challenges and opportunities. NDAS, this volume.
3. Harris, K.L. (1997) Geologic setting and prehistoric record of the Red River Valley. NDAS, this volume.
4. Hartman, J.H. (1997) (ed.) Symposium on the Red River flood of 1997 – Involving science in future watershed management decisions. NDAS, this volume.
5. Harrison, S.S., and Bluemle, J.P. (1980) Flooding in the Grand Forks–East Grand Forks area. North Dakota Geological Survey Educational Series 12, 66 pp.
6. Hansen, D.E., and Kume, J. (1970) The geology of Grand Forks County. North Dakota Geological Survey Bulletin 53, 76 pp.
7. Thorleifson, L.H. (1996) Review of Lake Agassiz history, *in* Teller, J.T., Thorliefson, L.H., Matile, G., and Brisbix, W.C. (eds.), Sedimentology, geomorphology, and history of the central Lake Agassiz Basin. Geological Association of Canada Field Trip Guidebook, pp 55–84.
8. Osborne, L.F., Jr. (1997) An overview of the Red River valley winter of 1996–1997. NDAS, this volume.
9. Folland, C.K., Karl, T.R., and Vinnikov, K.Y.A. (1991) Observation climate variations and change, *in* Houghton, J.T., Jenkins, G.J., and Ephramums, J.J. (eds.), Climate change – The IPCC Scientific Assessment. Cambridge University Press, Cambridge, pp 194–238.
10. Kroker, S. (1997) Archaeology and flood deposits at The Forks, Winnipeg, Manitoba, Canada. NDAS, this volume.
11. Hartman, J.H., Beck, D.L., Kuehn, D.D., Reid, J.R., and Reiten, J. (in press) Paleosols as proxy data for climate change — Interpreting Holocene deposits in the badlands and prairies of western North Dakota. Geological Society of America Abstracts with Programs 29(6).
12. Perkins, D. (1997) The hard path and the soft path to flood protection. NDAS, this volume.
13. Miller, L.G. (1997) Verbal communication. LTM Engineering, Inc., Phoenix Arizona.